CONSTRUCTION

For Atomic Bomb Production

CONSTRUCTION for production of the atomic bomb was probably the largest and most rapid coordinated building job ever undertaken. In less than three years, nearly $2 billion was spent for the materials and labor of construction, for process equipment, and for what undoubtedly is the greatest research and development program ever undertaken by any group under any conditions. Yet despite its size and speed of construction the project has been completely shielded from public knowledge, a blackout that still envelopes the manufacturing processes, but which is now lifted as respects the design and construction of the plant facilities themselves. The articles in this special issue comprise the first presentation of the construction story of the atomic bomb project.

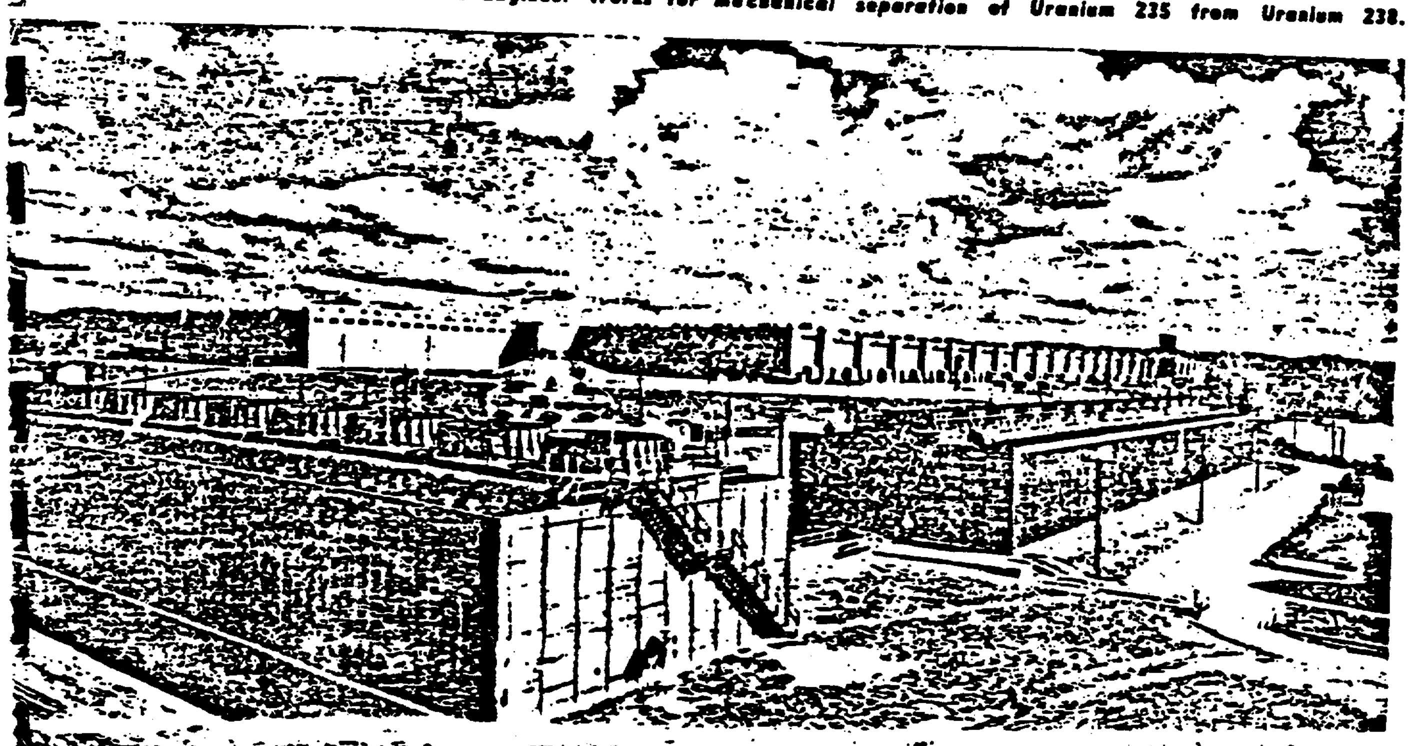
The principal facilities required to effect atomic fission and produce the bomb are located at three sites as follows: The Clinton Engineer Works near Knoxville, Tenn., which includes an electromagnetic plant, a gaseous diffusion plant and a thermal diffusion plant providing three processes for the separation of U-235, a "semiworks" or pilot plant for plutonium production and the town of Oak Ridge, all of which cost $1 billion.

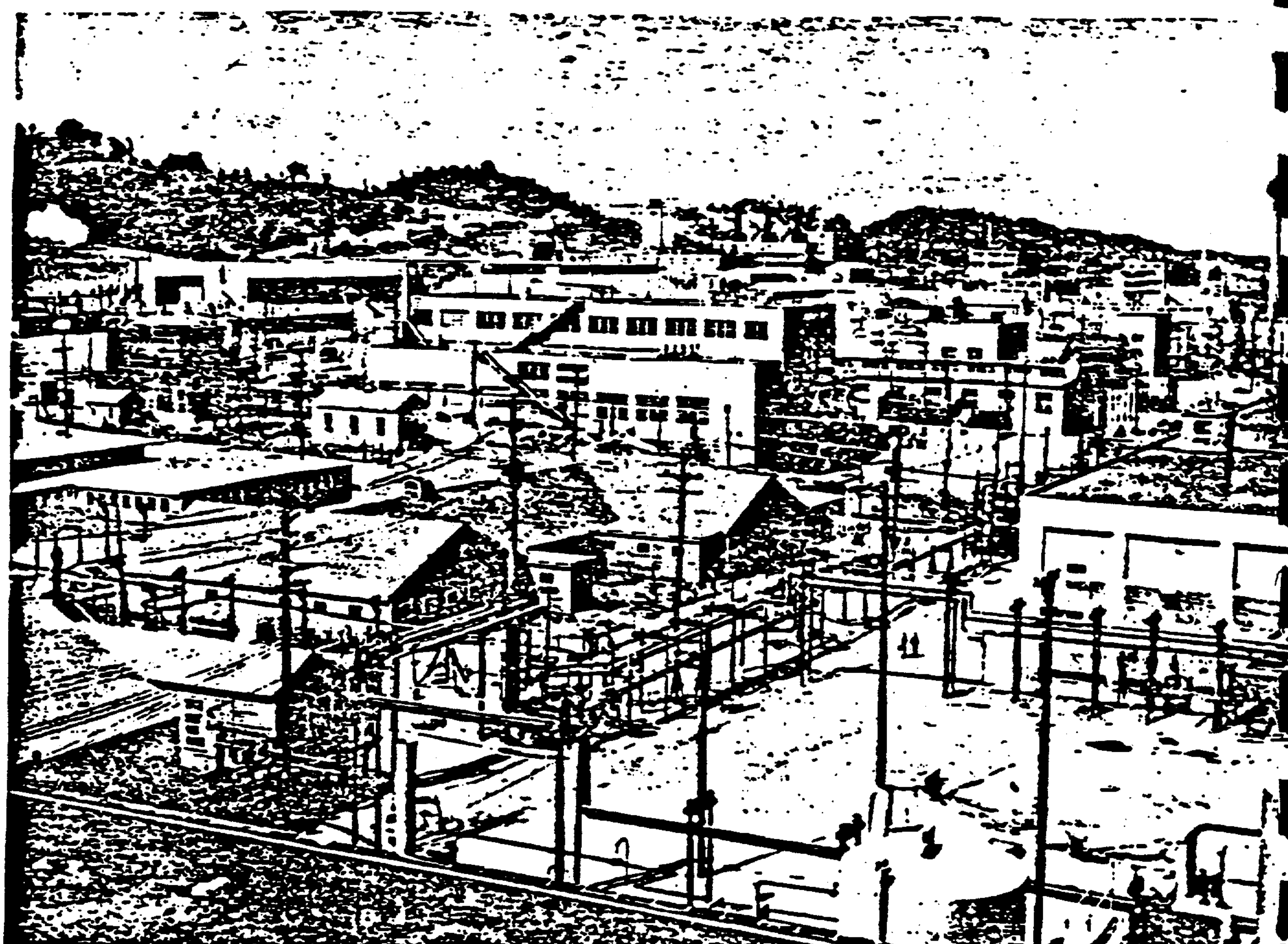
The Hanford Engineer Works in the state of Washington was built on a 400,000 acre site and 45,000 construction workers were employed to build a plutonium plant in 1½ years at a cost of $342,000,000. Research and bomb assembly facilities were provided at Los Alamos, near Santa Fe, N. M., to which materials made at the Clinton and Hanford works were shipped and which cost $55,000,000.

To appreciate the reason for, and to a certain extent the methods required for building these facilities a brief review of the history and the fundamental physics of atomic fission (see the 8-page insert on this subject in *ENR* Aug 31, 1945) will be helpful.

Scientists had learned by 1939 that atomic fission using uranium was possible, and its properties for military use were discussed at that time. However, studies of the means of separation into usable elements were for some time carried on only as individual scientific experiments. By the summer of 1940 the National Defense Research Committee had been formed, and with some money from the Army and Navy Departments, intensive research was started. By December, 1941 several universities and a few private laboratories were doing more

Gaseous diffusion plant at Clinton Engineer Works for mechanical separation of Uranium 235 from Uranium 238.





All pictures in this issue from Manhattan District, Corps of Engineers, unless noted

A large number of inter-related buildings was required at the Clinton Engineer Works for the electromagnetic process of separation of uranium isotopes.

or less coordinated work under contracts totaling about $300,000, and soon thereafter all efforts to produce an atomic bomb were consolidated under the Office of Scientific Research and Development.

By the spring of 1942 it was established that six separation or production methods were about equal as to possibility of success and all were nearly ready for pilot plant construction. These were: The centrifuge, gaseous diffusion, thermal diffusion and electromagnetic methods of separating U-235; and the uranium-graphite pile and the uranium-heavy-water pile methods of producing plutonium. Accompanying sketches show diagramatically the fundamental physics involved in these various methods.

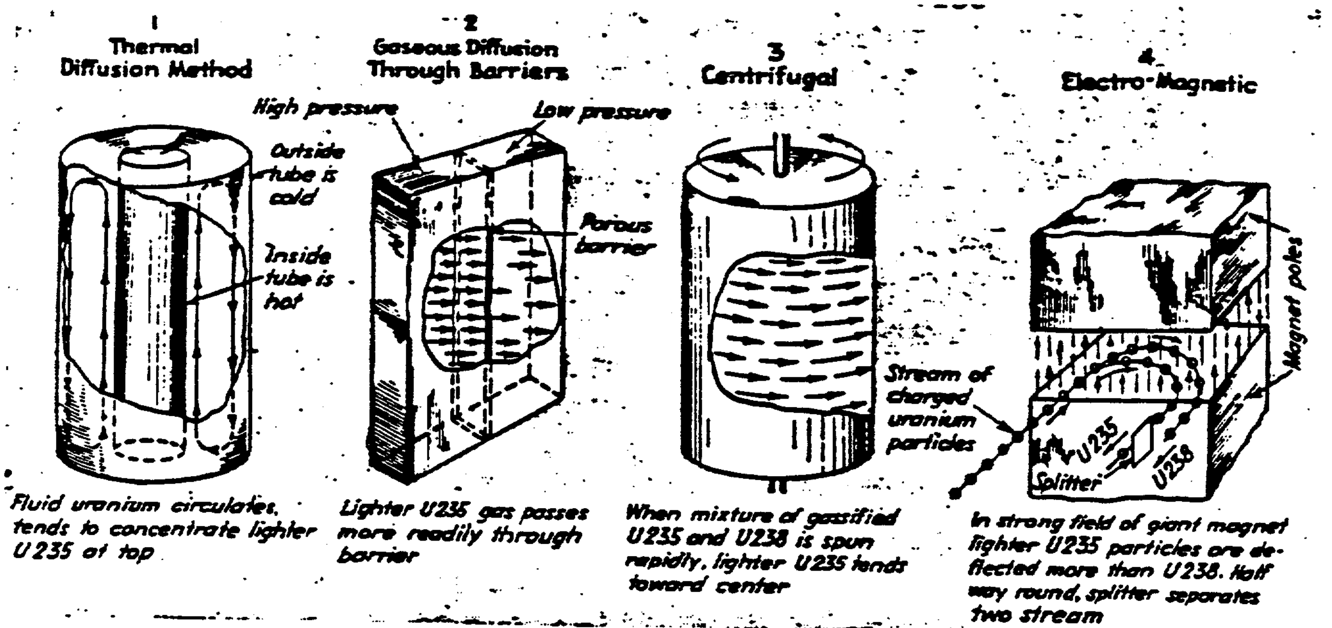
It seemed certain that if we could devise such a variety of ways of making the materials for an atomic bomb, our enemies also could find means of achieving the same end. And since it was known that the Germans were making progress in this direction and that an atomic bomb was one of the "secret weapons" that Hitler kept promising his troops, the urgency injected into our efforts is explained.

Production by several methods

Not enough scientific information was available, however, to estimate the relative merits of the several different production methods so that our energies could be concentrated on only one; and if we chose a less efficient or slower one than the Germans the results might be disastrous. Accordingly, there was no alternative but to develop simultaneously all of the plants. As it worked out, however, only three of the methods were brought to the large scale production stage; the centrifuge method for U-235 was used only in a pilot plant and the heavy-water pile method for production of plutonium was carried only to where it could safely be discarded in favor of the uranium-graphite pile.

As developments progressed beyond the experimental stage the Army Corps of Engineers was brought in to direct the construction of full scale plants, and in June, 1942, the Chief of Engineers instructed Col. James C. Marshall (now Brig. Gen. Marshall in charge of the Boston Port of Embarkation) to form the "Manhattan Engineer District," which for security was labeled the "DSM (Development of Substitute Materials) Project." In September Brig. Gen. (now Maj. Gen.) Leslie R. Groves of the Corps of Engineers was given full responsibility for activities relating to the DSM project, and in the spring of 1943 the Manhattan District took over all research and development contracts from the OSRD. Since that time all work on the project has been directed by the Manhattan District, carrying out the ideas of the scientists working on the project. General Groves' headquarters and a district liaison office have been maintained in the Office of the Chief of Engineers in Washington during the entire construction period.

The Manhattan District is unique



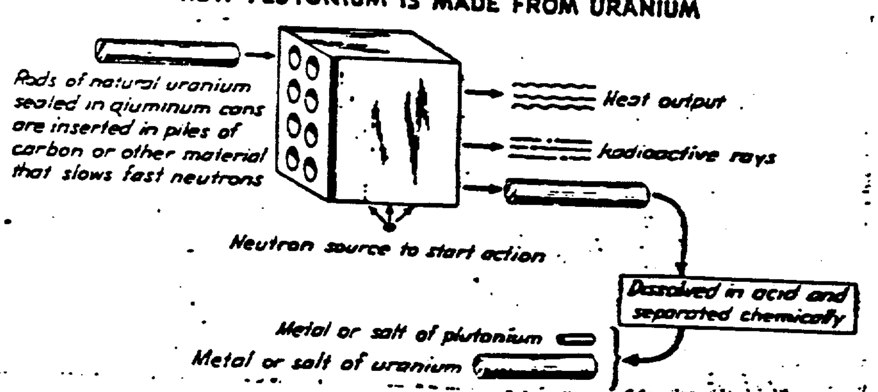
All methods of separating Uranium 235 from Uranium 238 increase the proportion of U 235 only slightly in any single operation, thus requiring an enormous number of cycles to achieve usable separation.

in the Corp of Engineers as it is an organization without territorial limits to supervise contracts for construction and operation in all sections of the United States and some parts of Canada, with other contracts covering an even wider field. Headquarters have been at Oak Ridge, Tenn., since August 1943 from which stemmed not only supervision of the Clinton and Hanford Engineer Works but that of the area offices as well. These latter offices, set up wherever required in the country were separate from the established geographical district offices of the Corps of Engineers so that knowledge of significant phases of the work could be restricted to a minimum number of persons. In many cases facilities of the normal district and division offices were utilized to purchase construction equipment and materials and to acquire land, but activities beyond these were handled within the separately established organization.

The Manhattan District, however, has functioned as do similar districts under the Chief of Engineers in making contracts and directing work. Most of the construction has been done under fixed-fee contracts, the Manhattan District selecting architect-engineer-manager firms who did some of the work with their own forces and contracted with others for materials and services, wherever possible on a lump-sum or fixed-price contract. The work accomplished at Clinton and Hanford in a three year period is the equivalent of building a Panama Canal each year.

The articles in this issue are concerned only with major construction in the United States under direction of the Manhattan District. Readers may note that nothing is presented relative to the construction of the facilities at Las Alamos, N. M. and that there sometimes seem to be omissions of detail in some of the other articles. These shortcomings result from security restrictions or just lack of space in telling a $1.500.000.000 construction story in a single issue. Beyond this, however, the issue will be found to unfold a construction story of uncommon scope and interest. As Col. Kenneth D. Nichols, district engineer of the Manhattan District since Aug. 1943, describes it, the atomic bomb project is an "accomplishment which will endure as a monument to the ingenuity, vision and determination of all those, from scientists to laborers, who have had a part in the work. These people and organizations—scientific, engineering, contracting, manufacturing, procuring and others—working in close harmony among themselves and with Government agencies deserve unlimited credit for the successful accomplishment of an almost impossibly vast and complicated task."

HOW PLUTONIUM IS MADE FROM URANIUM



Atomic energy can be released from plutonium, an element produced by man from uranium. Special shielding is required for protection against radioactivity.

Clinton—a Monument to Teamwork

Clinton Engineer Works, constructed at a cost of more than billion dollars, is composed of several huge plants built by the cooperative effort of some 47,000 persons— a great achievement

Col. Earl H. Marsden

*Executive Officer, Manhattan District, Corp of Engineers

MOST EXTENSIVE of the great industrial plants developed for production of the atomic bomb is the Clinton Engineer Works, which also has served as the headquarters of the Manhattan Engineer District. Three methods of separation of uranium isotopes are carried on at CEW—electromagnetic, gaseous diffusion and thermal diffusion, and in addition there is a pilot plant for plutonium production. Together with the city of Oak Ridge the Clinton facilities cost $1,000,000,000, thus, far exceeding the initial cost of any industrial plant anywhere in the world. More important, the plants stand as a monument to the imagination and clear vision of scientists, to the confidence of American engineers that no problem is beyond solution and to the ability of American construction men—laborers, craftsmen and executives alike.

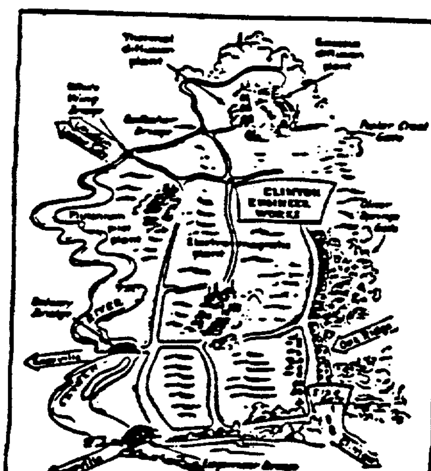
Clinton Engineer Works had to be safe from air attack, not too close to centers of population, and large enough to accommodate four separate plants. It had to have dependable electric power in large quantities, flat building areas separated by natural barriers, and a town site of at least 5.000 acres. And it had to be accessible to rail and motor transport, and on land of low agricultural value adjacent to a dependable water source.

Such a location was found along the Clinch River a few miles downstream from Norris Dam and 18 miles west of Knoxville, Tenn. Here, a rectangular area of 59,000 acres of marginal farm land with a washboard topography was acquired in the fall of 1942 at a cost of $2,600,000 under the cloak of the name "Kingston Demolition Range." The northeastern corner of the reservation was set apart as a site for the town of Oak Ridge, which was started in early 1943. South of the town were established warehouses, lumber and equipment yards, and beyond them were the plant sites.

Electromagnetic separation plant

The engineering-construction firm of Stone & Webster Engineering Corp. was chosen to design and construct the electromagnetic plant and to manage most of the "central facilities" construction, that is, the town and the utilities that served both it and the plants. The contract eventually called for plant construction estimated to cost in excess of $300,000,000, for which the design and construction firm received a fee of less than one percent.

Ground was broken for the first plant building in February, 1943 and the first production unit was in use by the operating contractor, the Tennessee Eastman Corp., in January, 1944. The peak of plant construction was reached in July, 1944 when a total of 13,200 construction workers were on the payroll. The electromagnetic process requires a large amount of electric power, which is provided by the Tennessee Valley Authority.



Clinton Engineer Works has three major plant areas and the town site—all separated by mountain ridges.

E. I. duPont de Nemours & Co. designed and built a small plutonium plant, now known as Clinton Laboratories, upon which the design of the Hanford Engineer Works is based. Interesting construction included an underground tank farm for the storage of radioactive waste.

Also, Haydite (burned clay), sand and barium chromate coarse aggregate were used for concrete shields in the process building to increase the absorption of lethal rays. The plant was started in February, 1943, and operation got under way in October of the same year. Construction cost was about $12,000,000, and peak employment reached 3,247. Until July, 1945, the plant was supervised by the University of Chicago and now is operated for experimental purposes by the Monsanto Chemical Corp.

Gaseous diffusion plant

In the spring of 1943, design work was started on a gaseous diffusion plant by the Kellex Corp., a unit of M. W. Kellogg Corp. of New York, which also handled supervision of construction and procurement of equipment. Chief construction contractor was J. A. Jones Co., Charlotte, N. C., while Ford, Bacon & Davis, Inc., designed, constructed and for a time operated an auxiliary 400x1,000-ft. plant to "condition" equipment before placement in the process plant. This entire plant is operated by Carbide and Carbon Chemicals Corp.

A high-temperature, high-pressure variable-frequency steam power plant was designed by Kellex Corp. and Sargent & Lundy of Chicago and constructed by J. A. Jones Co. at a cost

One of main buildings of the electromagnetic process with cooling towers in foreground. The end of the steel frame building was left open temporarily to facilitate installation of heavy equipment.

of $34.000,000. Generating equipment with a capacity of 238,000 kw. was installed. The paradox of this gigantic steam plant in the heart of the TVA region is explained by plant requirements for variable frequency current and necessity for minimizing possibility of interruption of power.

The distance of the gaseous diffusion plant from the town site, and the fact that all living quarters and eating facilities already were overcrowded, made necessary the establishment of a construction city, in addition to Oak Ridge. which reached a population of 12.000. The camp, complete with shopping and recreation facilities, was constructed by J. A. Jones Co. and Ford, Bacon & Davis.

The entire gaseous diffusion plant, including auxiliary plants but excluding the power plant, is estimated to cost $500,000,000. A labor peak of 25,000 was reached in May, 1944.

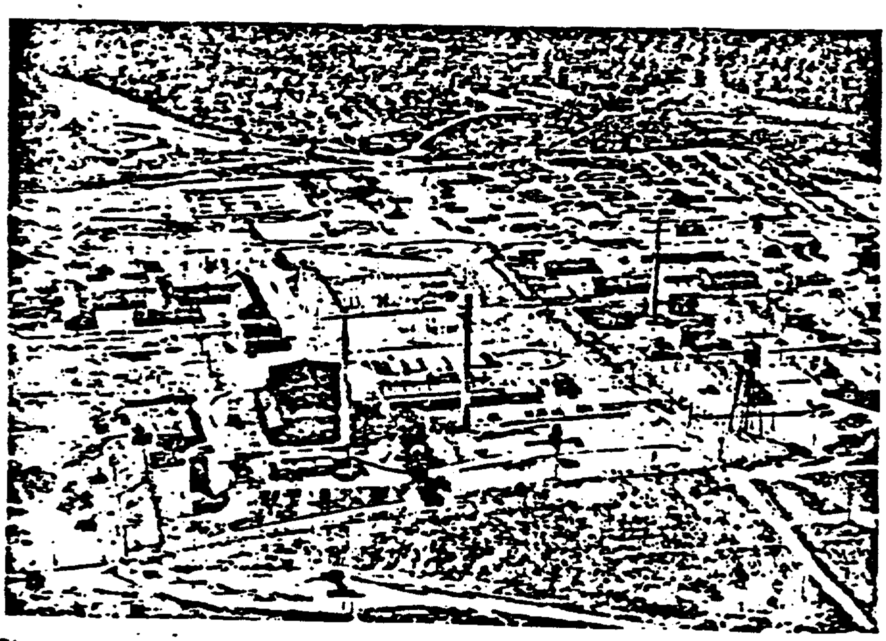
Thermal diffusion process

To provide enriched feed to the electromagnetic process, what is known as the thermal diffusion plant was constructed. The plant was designed and constructed by the H. K. Ferguson Co., Cleveland, with operation handled by a Ferguson subsidiary, Fercleve. This is a relatively small job in comparison with the other plants, the main building being 82x522 ft. Twelve oil-fired marine boilers, originally intended for destroyer escorts, were procured from the Navy and remodeled to supplement steam from the main power house. A tank farm of 6,000,000-gal. capacity was built for fuel storage. The entire job cost $10,500.000. and was built in five months, the first unit coming into operation in only three months.

The town of Oak Ridge, which was built from "scratch" in two and one-half years to become the fifth largest in the state, cost about an even $100,-000,000, including utilities and services for the town and the nearby electromagnetic production plant. Some 15,000 family units and 30,000 bachelor quarters were built on the area with all necessary commercial and social facilities. Oak Ridge was planned by Skidmore, Owings and Merrill, and built by contractors under the general direction of Stone & Webster Engineering Corp.

Labor was hard to get and to keep

A total of 110,000 construction workers was hired from the time ground was broken in November, 1942 until early August, 1945. The construction peak was 47,000, reached in April, 1944, while at the same time other personnel was working in the first units of the plant to be put in operation. Procurement of



Plant at Clinton Engineer Works built by duPont as pilot plant for plutonium process and now operated as "Clinton Laboratories".

this vast amount of labor was a major undertaking in itself, on which the War Manpower Commission and the United States Employment Service, as well as union leaders and their organizations, rendered herculean service to help the contractors and the Army secure workers.

Every reasonable effort was made to provide all the necessities and as many as possible of the niceties of life to attract workers and keep them on the project after they arrived. Living quarters of every type were constructed—from the war-engendered 16x16-ft. hutments through trailers, dormitories with steam heat and some with connecting baths up to spacious modern bungalows, justified to keep top scientists and their families happy. Surrounding towns were scoured for living quarters of all types. The Federal Housing Administration sponsored new housing in war-crowded communities and trailer camps were built on the area and mushroomed of themselves in the nearby territory.

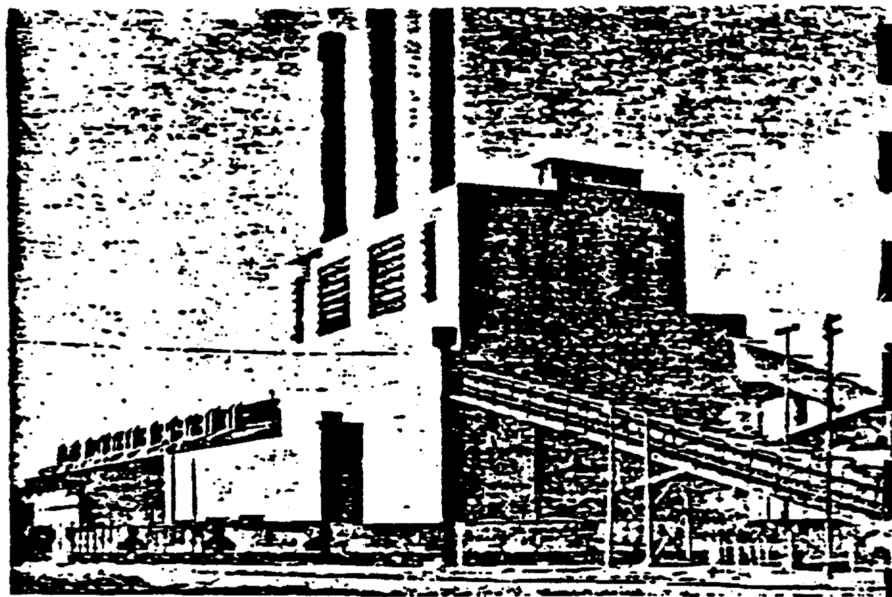
Panels of local rationing boards were established to help workers get gasoline and tires for "share-the-ride" clubs. A bus transportation system, which grew to one of the largest in the nation, was established to move workers to and around the work areas.

Nursery schools were established so that mothers would be able to take jobs. The Selective Service even deferred some laborers when they were essential to Clinton Engineer Works construction.

Safety emphasized

Clinton Engineer Works is justly proud of its safety record, achieved by wholehearted cooperation of all concerned, despite the accent on speed. At the end of August, 1945, after the expenditure of 218.000,000 man-hours on construction, the cumulative frequency rate (disabling injuries per million man-hours) was only 6.91 and the severity rate (days lost per thousand man-hours) was only 1.51. For comparison, the U. S. Department of Labor's national construction industry averages for the year 1944 were 27.70 and 3.68.

In addition, less than 0.06 percent of the total man-hours worked at Clinton Engineer Works were lost through labor disputes. Truly this is an achievement worthy of note, reflecting the cooperation of labor and satisfaction with efforts made to provide good working and living conditions.



Largest steam plant ever constructed in one operation supplies 238,000 kw. of power and process steam for Clinton Engineer Works. Black building at left is thermal diffusion plant.

The Clinton Engineer Works is a part of the "Manhattan Project" which is under the supervision of Maj. Gen. Leslie R. Groves. The Manhattan District of the Corps of Engineers is headed by Col. Kenneth D. Nichols, with the writer as his executive officer. Construction at CEW was started by Lt. Col. Warren George of St. Louis, Mo., continued under the direction of Col. Robert C. Blair of Urbana, Ill., Col. Thomas T. Crenshaw, of Watertown, N. Y. and Col. John S. Hodgson of Montgomery, Ala., successively. Through lack of space, credit cannot be given to all who had responsible positions on the project, but the accompanying partial list of outstanding executives is offered with the hope that readers will bear in mind that without the cooperation of thousands of others none could have accomplished his assignment.

TOP CONSTRUCTION PERSONNEL

Plutonium Pilot Plant		
	Contractor	E. I. duPont de Nemours & Co.
	Project Manager	J. D. Wilson
	Officer in Charge	Capt. James F. Grafton
Electromagnetic Plant		
	Contractor	Stone & Webster Engineering Corp.
	Project Managers	T. C. Williams Frank R. Creedon T. R. Thornburg
	Officers in Charge	Lt. Col. Warren George Lt. Col. W. E. Kelley Colonel John S. Hodgson Lt. Col. Mark C. Fox
Gaseous Diffusion Plant		
	Contractor	J. A. Jones Construction Co.
	Project Manager	Edwin L. Jones
	Officers in Charge	Colonel Walter J. Williams Lt. Col. William P. Cornelius
Conditioning Plant		
	Contractor	Ford, Bacon & Davis, Inc.
	Project Manager	C. C. Whittlesey
	Officer in Charge	Lt. Col. Curtis A. Nelson
Thermal Diffusion Plant		
	Contractor	H. K. Ferguson Co.
	Project Manager	C. W. Roberts
	Officers in Charge	Lt. Col. M. Fox Maj. T. J. Evans

Building the Hanford Plutonium Plant

Col. F. T. Matthias
Area Engineer, Hanford Engineer Works

● The plutonium production plant at Hanford, Wash., was put in production in little more than a year in a "sagebrush and sand" area selected largely because it had good cooling water from the Columbia River and available electric power from the Bonneville Power Administration. Construction camps were provided for 40,000 workers and a permanent town for 17,000 operators and their families. Unusual concrete and steel structures were built to confine radiation. Gravel and sand aggregates were dug and processed at the plant site; concrete was mixed in central plants and delivered chiefly by pumps to construction areas.

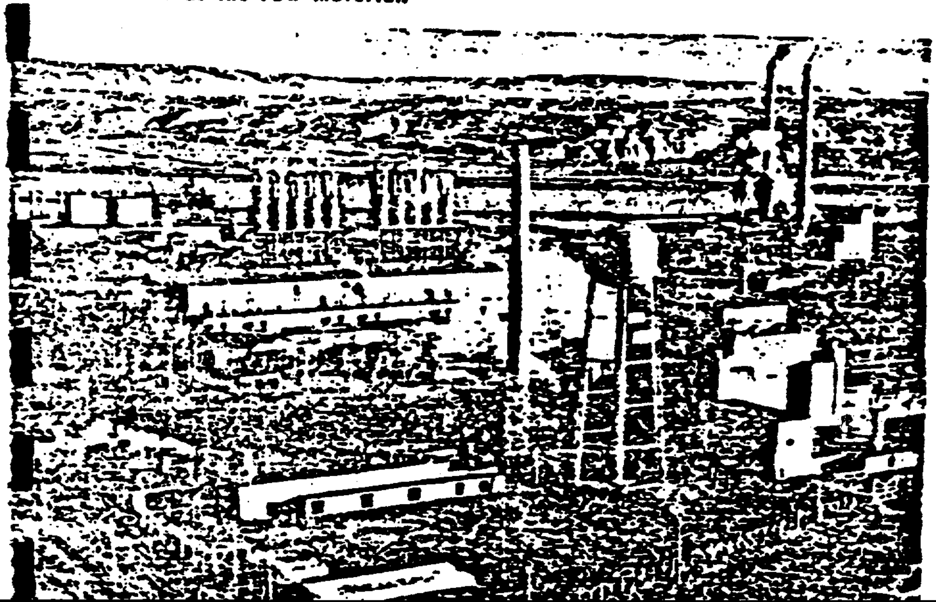
THE HANFORD Engineer Works, located along the Columbia River in eastern Washington, is one of the three major plants under the Manhattan Engineer District, built and operated for the production of the atomic bomb. The plant is devoted entirely to the production of plutonium atoms, using U-238 as the raw material and U-235 as the energy source for what is probably the world's greatest atom-making factory.

The project, as completed, includes seven major manufacturing areas, an operating village and administrative headquarters as well as all of the service facilities required for manufacturing processes in an area more than 600 sq. mi. in extent. The actual production units at Hanford are several huge uranium "piles." Each pile is a very large block of graphite with holes in which are placed uranium-metal cylinders, sealed in aluminum cans to protect the uranium from corrosion by the cooling water constantly pumped through the pile.

Work was begun on the first of the Hanford production piles on June 7, 1943, and operation of the first pile began in September, 1944, followed, during the fall of 1944 and the early months of 1945 by the second and third piles. The site was originally laid out for five piles, but construction of only three has been undertaken.

Besides the piles, there are plutonium separation plants, pumping stations and water treatment plants. There is also a low-power chain reacting pile for material testing. Not only are the piles themselves widely spaced for safety and mutual protection, but the separation plants are well away from the piles and from each other. The administrative and living quarters are situated many miles from all process areas.

One of seven major plant areas at Hanford for production of plutonium, using Uranium 238 as the raw material.



Utilities were a major project

With 158 mile of railway, 386 miles of highway, 52 miles of 230 kv. transmission lines, a water distribution system ranking in magnitude with the large metropolitan areas, construction housing for 40,000 and a village for 5,500 operating employees, and their families, the Hanford Engineer Works presented a large and difficult construction program, even without the seven complicated and massive plant structures whose construction and operation made the rest of the facilities necessary.

The plant was designed, constructed, and is now being operated by E. I. duPont de Nemours & Co., under contract with the Corps of Engineers for a total fee of $1. The prime contractor assumed general supervision of all construction, but wherever practicable subcontracted the work to utilize the administrative forces and the know-how of as many contracting firms as possible. Wherever plans and specifications could be prepared, work was done on a lump-sum or unit-price basis, but some necessarily was done under fixed-fee contracts.

The thing that has made construction at Hanford different is radiation from the breakdown of atomic nuclei generated within a pile operating at high power level, which is so strong as to make it quite impossible or at least seriously hazardous to permit any of the operating personnel to be exposed to its direct action. The whole of a power pile, therefore, had to be inclosed in very thick walls of concrete, steel or other absorbing material. At the same time it had to be possible to load and unload the piles through these shields and to carry the water in and out. Moreover, the shields must not only be radiation-tight but gas-tight since air or other gases exposed to the radiation in the pile would become radioactive.

Water needs tremendous

The water mentioned is needed to dissipate the thousands of kilowatts of energy, in the form of heat, generated in each producing pile. Requirements for this are comparable to that for a moderate-sized city, and pumping stations, filtration and treatment plants had to be provided. Furthermore, the system had to be a very reliable one; it was necessary to provide fast-operating controls to shut down the chain-reacting units in a hurry in case of failure of the water supply.

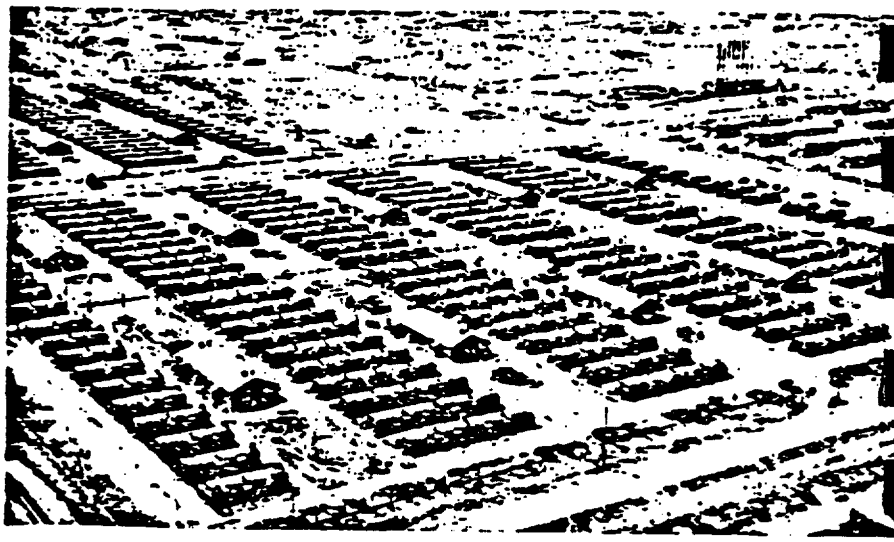
Radiation dangers that require shielding in the piles continue through a large part of the separation plant. Since the fission products associated with the production of plutonium are highly radioactive, uranium, after ejection from the pile must be handled by remote control from behind shielding, and must be shielded during transportation to the separation plant where the "slugs" must be processed by remote control in shielded compartments. The general scheme followed was to build a "canyon" consisting of a series of compartments with heavy concrete walls arranged in a line and almost completely buried in the ground.

Ideal site for project

The site selected for this construction had several desirable characteristics:

1. The Columbia River, flowing through the site, is probably unequalled for purity and cleanliness as a source for the large supply of water needed.

2. Transmission lines of the Bonneville Power Administration crossed one corner of the area and provided convenient and easy access to a large, dependable power source.



Hanford camp administrative center (top). The construction administration building is in the foreground and the hospital is at the right center. Women's barracks are at the far right and mens' at the left center. Portable "Pacific Huts" (below) were used for the last increment of housing, 900 ten-man huts being made to accommodate 10,000 men.

3. Unlimited deposits of gravel proved a good source of aggregate.

4. Rainfall in the area is less than 6 in. annually, and mud, which so often immobilizes construction activities, is almost unheard of.

5. The climate, while it has extremes of heat and cold, is generally mild in winter and does not seriously hamper construction.

6. Only a narrow, irrigated area along the river was tilled and, considering the size of the site, its procurement and development displaced only a small number of people and put very little agricultural land out of production.

The job of construction was the equivalent of seven major industrial plants, and cost $350,000,000. Some idea of its magnitude is conveyed by the following partial list of standard construction equipment used at Hanford:

Road vehicles including sedans, station wagons, carryalls, panel trucks, pickup trucks, jeeps and other types of military cars totaled 1,800. Some 900 buses were used during the peak of construction, with a total seating capacity of 30,300. There were roughly 1,900 dump and flat-bed trucks; 437 crawler tractors; 240 tractor and trailer units; 147 transit-mix trucks; 29 fire trucks and 20 ambulances; 9 small portable batch plants and bin setups, excluding the main concrete mixing plants; 44 rail-

Many a hotly contested baseball game was played on this diamond at Hanford. The principal league series included teams representing the different construction crafts. These games and other athletic events occupied the spare time of thousands of workers.

road locomotives and 460 railroad cars including flat, gondola, bottom-dump and hopper-bottom types; 311 crawler cranes; 5 locomotive cranes; and 4 stiff-leg derricks.

Earth moving was a big job

Another measure of magnitude is by quantities of earth and concrete handled. For example, some 25,000,000 cu. yd. of earth was moved in connection with the construction of the principal building, 386 miles of highways and 158 miles of railroads. All of this work was done by subcontractors, and except for the large volumes involved was not difficult since the soil could readily be handled by scrapers and draglines supplemented by power shovels for trimming excavations for buildings.

It was originally estimated that well over a million yards of concrete would be required, but as design progressed this figure was reduced, and a total of 780,000 cu.yd. of concrete was actually placed, mostly in six buildings, requiring over 100,000 cu.yd. each.

Aggregate production and furnishing concrete were included in a single subcontract. The subcontractor erected two aggregate production plants; one near Hanford at the east and one near Haven at the west of the project area. Both were over extensive gravel beds and were conveniently close to the existing railroad. The Hanford plant produced 500 to 600 tons per hr. and the Haven plant 350 to 450 tons per hr., each providing three sizes of coarse aggregate and two of sand. The plants were located near the Columbia River and screening was done wet, with the sand separated wet in screw classifiers.

Material from each pit was delivered first by bulldozer and later by wheel scraper to hoppers in the pits that fed a belt conveyor carrying material to classifying screens. All material handling through the aggregate plant was by belt conveyor, and with classified material stored radially. Live storage at each plant was about 60,000 tons. Material was reclaimed from storage by belt conveyors operating in tunnels under each pile of stock material and loading into elevated hoppers that fed directly into railroad cars or trucks. The contractor elected to operate the two plants alternately at full capacity rather than simultaneously, and built a considerable stock pile at each of the plants in advance of active concrete operations.

All concrete plants different

Five concrete mixing plants were obtained by the subcontractor, and they were used in six locations, one of the plants being used twice. Of the five plants, three had two 2-cu.yd. tilting mixers, giving a capacity of 150 cu.yd. per hr., and two had two 3-cu.yd. mixers giving a capacity of 200 cu.yd. per hr.

The mixing plants were second hand and each came from a different job so there was no uniformity in the batching methods. One plant was completely automatic in its control of batch quantities and mixing time and was manually operated through a push button control system.

Cement handling facilities

At each mixing plant setup cement handling facilities included live baching storage of from 400 to 600 bbl. At two areas an additional 3,000-bbl. silo was erected to permit immediate unloading of railroad car deliveries. Unloading arrangements were provided to accommodate either hopper-bottom or box cars. Cement was elevated into the mixing plant bins or into the silos by means of a bucket elevator. Aggregate was delivered to the plants by belt conveyors feeding from under-track hoppers into which the five classes of aggregate and sand were delivered by railroad car and, in some cases, by truck.

Each concrete plant was equipped with a belt conveyor that fed mixed concrete into hoppers of concrete pumps delivering through pipelines to the points of placement. Each plant also was equipped with a hopper and delivery chute to batch materials into transit-mix trucks for mixing while hauling to isolated locations where only small volumes of concrete were required.

The prime contractor operated the transit-mix trucks and the concrete pumps and also handled the 7-in. distribution pipe lines. Although this is perhaps the largest amount of concrete ever placed under such a dual arrangement, close and effective coordination of the two organizations resulted in an efficient and smooth operation that was outstandingly successful.

Practically all of the concrete placing on the project was for building construction, with only a small part of it in mass sections. Much of it had to be placed in confined spaces and with small clearances. In all of these locations the concrete was thoroughly vibrated into position with pneumatic or electric vibrators, with careful attention given to vibrating methods and the vibrating time to assure dense concrete to avoid radiation leaks as well as to assume structural adequacy. Even in the mass concrete sections the reinforcing steel required made clearances small and complete compaction difficult.

A difficult concreting problem

Typical of the problems successfully met was concreting a roof section of a building with no intermediate support between walls 60 ft. apart. Special travelling forms were built, similar in principle to those used for tunnel lining. They were moved on the crane tracks installed near the top of the building walls for permanent use. The form assembly was jacked up to position, concrete placed and after it had hardened, the jacks were released to lower the forms for moving to the next bay. These forms were moved along the top of the building until the 3-ft. thick top slab was completed along the entire 800-ft. length. Three buildings of this type were built, the same set of forms serving for all of the structures.

Many construction materials and some steel shapes had to be fabricated on the job. The prime contractor set up a shop for the fabrication of some very large T-beams of heavy steel sections, roughly 4 ft. x 4 ft., and all the material for all of the areas involved was assembled and prefabricated for erection at this shop.

Concrete pipe made on the job

Subcontracts were let for the extensive water distribution system. The sub-contractor providing the concrete pipe elected to manufacture the pipe on the site, which was accomplished by spinning concrete onto hoop reinforcing and curing the finished pipe in steam. A number of buildings in the plant were built with steel framing and concrete block, and this block was also fabricated on the site under a sub-contract.

Where it seemed desirable, central shop facilities were set up to prefabricate and prefit materials that had to go into the process buildings. This served the double purpose of concentrating skilled workmen on this duty and of speeding up the completion of the buildings by eliminating field fitting. The latter was a particularly important requirement as the tolerances for a substantial volume of the construction was on the order of $\pm .003$ in., equivalent to precision machine shop work. Much of the large and heavy equipment also had to be rigged and fitted to similar tolerances to permit remote control installation and removal.

A common construction problem that was unusually difficult to overcome at Hanford was servicing and maintenance of equipment. Practically all of the construction machines used were acquired from surplus stock at other Corps of Engineer projects that were being completed. These machines were of every make, size and type, making the job of servicing and maintaining stocks of repair parts very complicated. Also, getting and keeping mechanics who were capable of handling such diversified repairs and maintenance was a problem in itself.

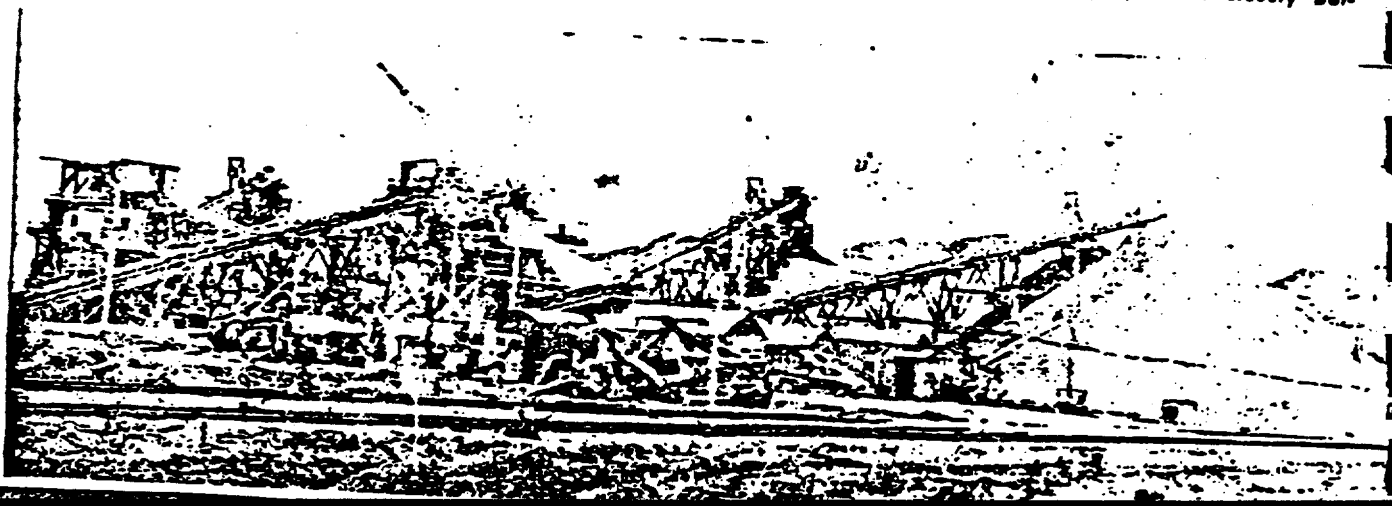
An area near the "center of gravity" of the construction project was selected as the site for the central repair shops.

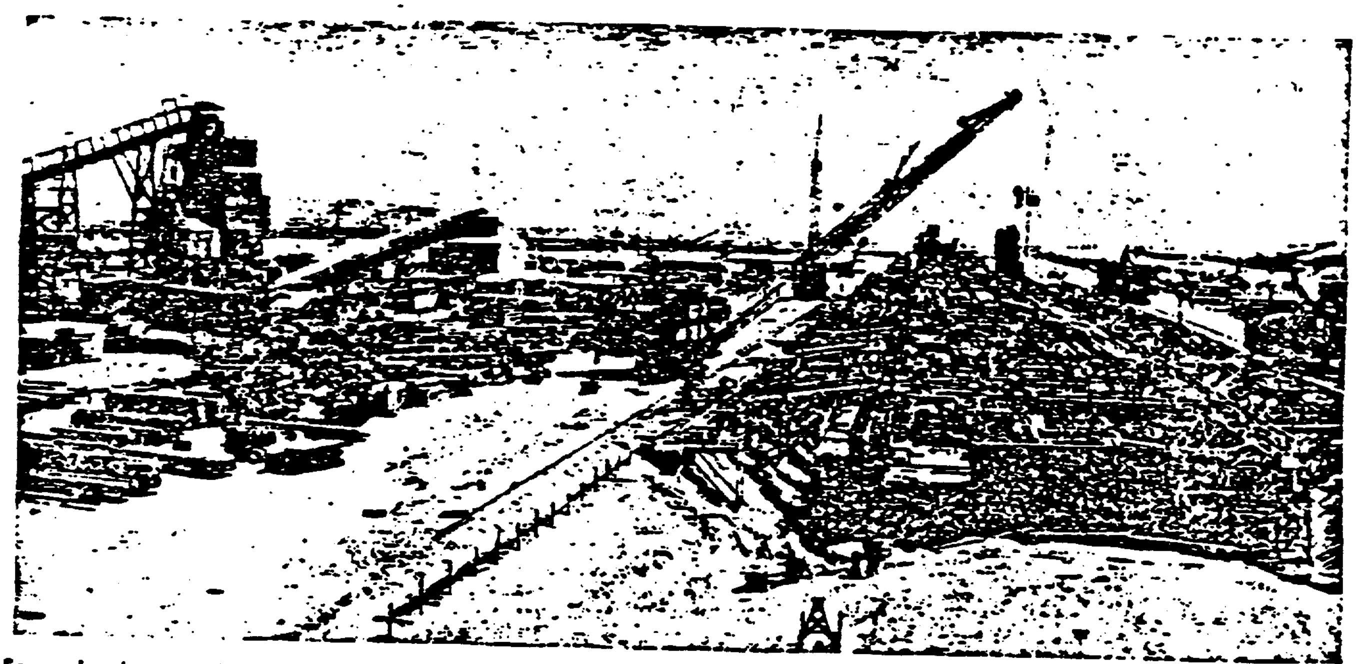
In addition, to prevent so far as possible the need for repairs, 270 grease and fuel trucks were used on field inspections and for servicing vehicles and equipment. Automotive equipment was checked periodically, as well as after designated lengths of service. For example, dump trucks were serviced every 250 miles or every three days, whichever occurred first; flat trucks every 500 miles or every five days; pickup trucks every 750 miles or every ten days; sedans, station wagons etc., every 1,000 miles or every 15 days.

Heavy equipment maintenance

The heavy equipment lubrication program involved oil changing and air and oil filter changes and greasing, all of which were set up on separate schedules. Tractors, motor patrols and other items of heavy construction equipment were greased at the close of each shift. Oil changes were made every 56 hr. of operation. Other types of equipment, such as

Aggregate production plant at the west end of the project. Natural aggregates occurred in proportions closely balanced to the concrete requirements.





Forms in place ready for concrete in the substructure of one of the massive buildings. Concrete was delivered by pipeline from mixer plant and pump building at left. Forms were built in panels and reused for other similar structures.

welding machines, light plants, air compressors and pumps, were greased periodically as determined by their gasoline consumption.

The labor force for construction at Hanford reached a peak of 45,000, for most of which it was necessary to provide living quarters. Some found existing accommodations in the surrounding area, and the Public Roads Administration and the Washington Department of Highways cooperated to improve roads around the area to increase the travel radius. But there were not adequate living facilities in the sparsely settled area, and a major construction camp, equivalent to an army cantonment, had to be built to meet housing demands.

Housing for 39,000 persons

A single camp was decided upon as offering much more in the way of flexibility and efficiency than would establishment of separate camps at each of the major production areas. The unincorporated village of Hanford (1940 population 436) located about six miles from the nearest plant unit, 25 miles north of Richland and 40 miles from Pasco passenger railhead for the project, was selected as the camp site. The area was almost flat with a slight grade toward the river, thus permitting drainage without pumping to near the river, where settling basins and treatment works were established. All of the central administrative facilities for the construction of the project were established at Hanford.

First housing was barracks for men, buildings 30x130 ft. set up in groups of four, with a common bathhouse for each group. Buildings were of light frame construction with a wallboard exterior and were partitioned into rooms for two men each with a general lounge room, which later was modified to permit additional housing. A total of 131 such barracks was built to provide space for 24,000 men.

Barracks for 5,000 women

Similar barracks were built for women, except that the rooms were slightly larger and only two buildings were connected to a common bath and laundry. Here again the original lounge room was later utilized for dormitory space to accommodate the peak of construction population, which included some 5,000 women.

Later, 900 huts, 16x40 ft. in plan, of arch type, plywood portable units used in war theaters, were purchased and erected at the camp. Each of these huts housed ten men, and a group of 20 huts was served by one toilet and bathhouse. During the peak of construction, these buildings also were crowded; at one time almost 10,000 men were housed in the 900 arch-type huts. Thus, a total of 39,000 individuals were housed at the peak of construction.

On the large construction jobs in the West in recent years, many construction workmen have learned to provide their own housing in the forms of privately-owned trailers. In line with this practice, a large trailer area was laid out at Hanford with a definite space for each unit and a central bathhouse and laundry provided for each group of about 30 trailers. Water connections were furnished for each trailer and a light frame shed with a paper cover was erected to give protection from the sun during the hot and dry summer period.

Trailers were also popular

The trailer camp at its peak accommodated 4,300 privately owned units. The peak of trailer housing at the Hanford camp, however, came several months after the peak of the employment as the trailer camp occupancy was building up even while other housing was being vacated.

Studies as to attendance, turnover and length of time on the job indicated that the workers in the trailer camps were by far the most contented group at Hanford, were contributing less to absenteeism and appeared to be doing the most efficient productive work. People in the trailer camps took great pride in the neat appearance of the area and developed a civic interest that resulted in quick establishment of all activities of a normal community.

An entirely separate city, in the

Richland area, was built to house operators of the production plants. Here, some 2,500 conventional type house units, 45 dormitories, store and commercial facilities, churches and schools, were constructed, almost all of the wood-frame type. Many parts of this construction were preassembled with millwork fabricated at a plant erected on the site.

In addition to the 2,500 conventional houses, about 1,800 prefabricated houses were erected. These "prefabs" were assembled at a mill some 300 miles from the site and were brought in on trucks and erected on prepared foundations. Streets, walks, playgrounds and all utilities were constructed to provide for normal small city needs.

Housing at Richland was subcontracted, with the prime contractor performing the administrative and control work as well as inspection. This subcontractor for the village handled practically all of the specialty work by sub-subcontract, requiring extensive coordination of all types of activities in the Richland area.

With construction areas four to eight miles apart, the "center of gravity" of construction areas some ten miles from the construction camp, with one major construction job located about 20 miles from the center of gravity and the village of Richland about 25 miles from the main group, the problem of central control of construction operations was exceedingly complex. The entire operation was administered from Hanford headquarters with most service functions centralized in one office to insure maximum benefits to all plant areas.

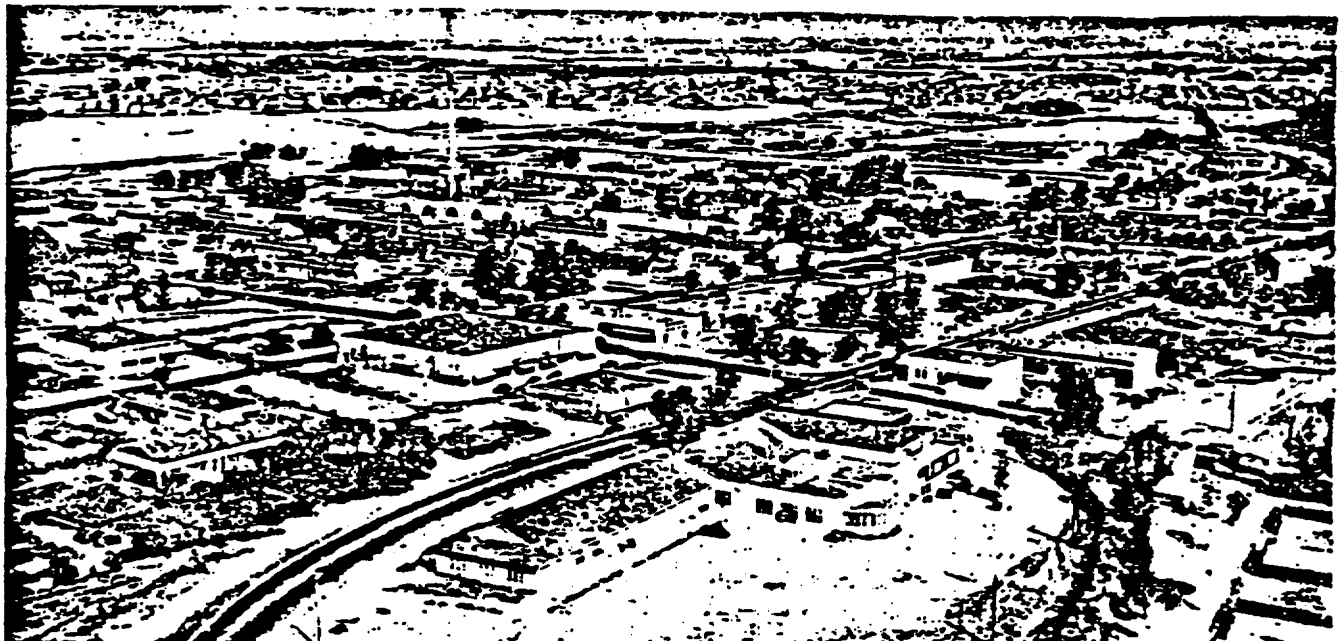
DuPont construction organization

The construction division of duPont was organized with a field project manager in charge, while assistant field project managers and a field superintendent headed up each of the various phases of the work such as control, service and engineering. Planning and scheduling of work was under the direct supervision of the field superintendent who reported to an assistant field project manager in charge of control. Actual prosecution of work in the field was under the supervision of craft superintendents who reported to the field superintendent. Inspection was directed by an assistant field project manager in charge of engineering.

Moving men and materials

Moving of men and materials was under the control of a transportation superintendent who reported to the field superintendent. All material came into a central receiving station, was requisitioned by the various areas and delivered by the transportation department.

Men were dispatched to various areas from the construction camp under the supervision of the field superintendent. By this means the assignment of men of various crafts to work in the areas where they were needed most could be coordinated for the entire job, with men drawn from the Hanford construction camp to meet each area's requirements. Actual job control in the field was handled by breaking down every item of work involved in the construction of an area, making up estimates of manpower requirements, scheduling each item of work and assigning it to the



Richland, the operating headquarters and housing area for project employees, was built on the site of the former village of Richland. The administrative area is in the center of the picture. The low land beyond the administration area was below maximum flood stage of the Columbia River and was not used for building sites.

proper craft superintendent for accomplishment on a coordinated craft basis.

All of the construction facilities at the Hanford camp were under the control of a service superintendent who handled housing and feeding, commercial leases and other matters pertaining to that area. The actual camp services were performed by a subcontractor who reported to the prime contractor. These included rental and collection of rents for barracks rooms, feeding and administration of the camp. About 25,000,000 meals and box lunches were prepared and served by the housing and feeding subcontractor during the construction program.

Safety made to pay

Through all phases of the construction operation considerable attention was given to safety and morale maintenance activities. Every effort was made to educate workmen in safe practices and to avoid carelessness in all of their activities. No one was allowed in the building construction areas without a safety hat. To help induce the employees to wear safe clothing, a trailer was fitted as a store and taken to convenient points to sell safety shoes and gloves.

Men who performed their work according to safe methods earned individual safety awards. These were made on the recommendations of the supervisors, and were based on daily observation of safe work practices over various periods of time and for special contributions to safety. Safety meetings were held frequently.

A safety engineer in the contractor's organization exercised his influence through officials in various supervisory positions. The project made an enviable safety record with ratings, based on the National Safety Council system of an accident frequency of 5.99 percent and an accident severity of 1.30 percent. Sixteen fatalities occurred, eleven as a result of two serious accidents.

BUILDERS OF THE HANFORD ENGINEER WORKS

PRINCIPAL CONSTRUCTION SUBCONTRACTORS

Firm	Home Office	Class of Work
Smith, Hoffman & Wright	Portland, Ore.	Housing
Hanford Concrete Contractors	Winona, Minn.	Ready-mix concrete
Myers Bros.-N. M. Ball & Sons	Los Angeles	Excav. & Road Const.
Morrison-Bechtel-McCone	Boise, Idaho	Composite tanks
Twaits-Morrison-Knudsen	Los Angeles	Housing & utilities
Guy F. Atkinson Co.	San Francisco	Channel excav. & R. R.
Guerin Bros.	San Francisco	Excav. road & R.R. Const.
Clinton Bridge Works	Clinton, Iowa	Structural steel
*Olympic Commissary Co.	Chicago	Commissary operations
*Newberry-Chandler-Lord	Los Angeles	Electrical work
*Hankee-James-Zahniser & Warren	St. Paul	Piping work
G. A. Pehrson	Spokane, Wash.	Arch.-Engr. services
A. A. Durand & Son	Walla Walla, Wash.	Drilling of wells
American Pipe & Constr. Co.	Los Angeles	Reinforced concrete pipe
National Gunite Contracting Co.	Washington	Gunite reservoirs
Erie City Iron Works	Erie, Pa.	Boilers
Combustion Engr. Co.	New York	Boilers
Chicago Bridge & Iron Co.	Chicago	Elevated steel tanks
Link-Belt Co.	Philadelphia	Coal handling systems
Rush Engineering Co.	Pittsburgh	200-ft. chimneys

** Cost-plus-fixed-fee contracts. All others lump-sum or fixed price.*

TOP DU PONT CONSTRUCTION MEN

E. G. Ackart	Chief Engineer
G. M. Reid	Assistant Chief Engineer
M. F. Wood	General Manager Constr. Div.
F. H. Mackie	Manager, War Construction
T. W. Brown	Chief Accounting Officer
G. P. Church	Field Project Manager
T. L. Pierce	Asst. Field Project Manager
G. E. Bubb	Asst. Field Project Manager (Construction)
W. V. Krewatch	Asst. Field Project Manager (Engineering)
G. E. Hillman	Asst. Field Project Manager (Control)
L. S. Grogan	Field Superintendent
E. L. Pleninger	Service Superintendent
B. M. Taylor	Housing Superintendent

PRINCIPAL CORPS OF ENGINEER OFFICERS

Col. Franklin T. Matthias	Area Engineer
Lt. Col. Harry R. Kadlec	Chief, Construction Division (deceased)
Lt. Col. Benjamin T. Rogers	Chief, Construction Division
Maj. Richard F. Ebbs	Executive Officer (during construction)
Maj. Harry D. Riley	Chief Engineering and Services
Maj. Joseph F. Sally	Chief of Operations
Maj. William L. Sapper	Area Eng., Wilmington, Del. Office
Maj. Frank P. Erichsen	Pile Area Construction

Leisure time opportunities

Security surrounding the project made it difficult to impress on the workers the importance of the job and to glamorize the part they were playing in the war. As an alternative it was determined that the most effective way to keep people at the project was to make off-hours living easy and enjoyable with opportunities for education and recreation. Recreational facilities were established in the construction camp to perhaps a greater extent than has before been done on a construction project.

Foremen were urged to watch their men and be sure that none was being kept on work for which he was not suited. Also, information services were established in the personnel department of the prime contractor where employees could get help and counsel on any problems that might be bothering them.

For the Corps of Engineers Maj. Gen. Leslie R. Groves was responsible for the project as part of the Manhattan Engineer District program that was under the direct control of Col. Kenneth D. Nichols, district engineer. The writer was area engineer, contracting officer and commanding officer on the project.

Photo by Thompson, Knoxv

A section of the electromagnetic process plant at Clinton Engineer Works built by Stone & Webster Engineering Cor

Men and Materials for a $427,000,000 Jo

● ***Stone & Webster assembled what is probably the most diversified engineering and construction organization ever to work on a single project when they built the electromagnetic plant and the city of Oak Ridge. The problems of procurement and handling of materials were often unique and always difficult of solution. How this was handled constitutes an important chapter in the story of production of the atomic bomb.***

A GIGANTIC PLANT consisting of 175 separate buildings, including nine major processing structures, was constructed at the Clinton Engineer Works for electromagnetic separation of the isotopes of uranium. This plant and living facilities at nearby Oak Ridge were constructed by Stone & Webster Engineering Corp. under what is believed to be the largest design and construction contract ever awarded to a single firm. First and all-important in developing the design for the electromagnetic process as well as in building the plants and the City of Oak Ridge, was procurement and assignment of personnel. Coupled with this was the purchasing, expediting and handling of the necessary materials.

A brief statement of just what is accomplished by the plant helps in an appreciation of its complexity and size. Its purpose is to separate U-235 from U-238 (which is found in nature in a ratio of 1 to 140) by forcing a stream of molecules at high speed through the field of a powerful magnet. The lighter U-235 particles form a curve of shorter radius than the curve formed by the U-238 particles, and by catching in different containers the isotopes thus partially separated, U-235 of high purity can be produced.

The ionized particles to be separated must travel in a very high vacuum or they will be deflected by collisions with molecules of air. To provide almost a perfect vacuum, pumps of much higher speed and lower pressure than were ever previously developed for commercial purposes are required. Extremely accurate control equipment for the high voltage current is necessary to maintain constant conditions in the magnetic field, for if this varies, the curvature of the streams of particles will vary and the entire operation will be futile.

Procurement and assembly of this unprecedented equipment, as well as design and construction of the unusual buildings to house it, and utilities to connect and service it were handled by the Stone & Webster En gineering Corp. as engineers and co structors. Basic process design w formulated by scientists at the Rad tion Laboratories at the University California, with whom Stone & We ster men worked to translate ide into the production plant. The c tinuing job of operation is done the Tennessee Eastman Corp., whic collaborated with Stone & Webster check and perfect the design. Pr lems on specialized equipment we worked out jointly with Allis-Cha mers Co., Westinghouse Corp., Ge eral Electric Co. and many other ma ufacturers.

Work supervised or done directl by Stone & Webster's own forces h a total value of $427,000,000, inclu ing the purchase of equipment for th plant and construction of most of t city of Oak Ridge, which had a pe population of nearly 75,000.

Secrecy paramount

Plant construction, and to some e tent even the housing, was accom plished under the handicaps of a re markably successful secrecy contro

This control made it necessary set up an independent engineering or ganization with representation at sev eral locations to cover direct contac with the physicists, chemists, opera tors and constructors at the job site with only a *selected* few having com plete knowledge of what was to be ac complished. Upon these few wa placed the responsibility of coordi nating the parcelled-out portions o

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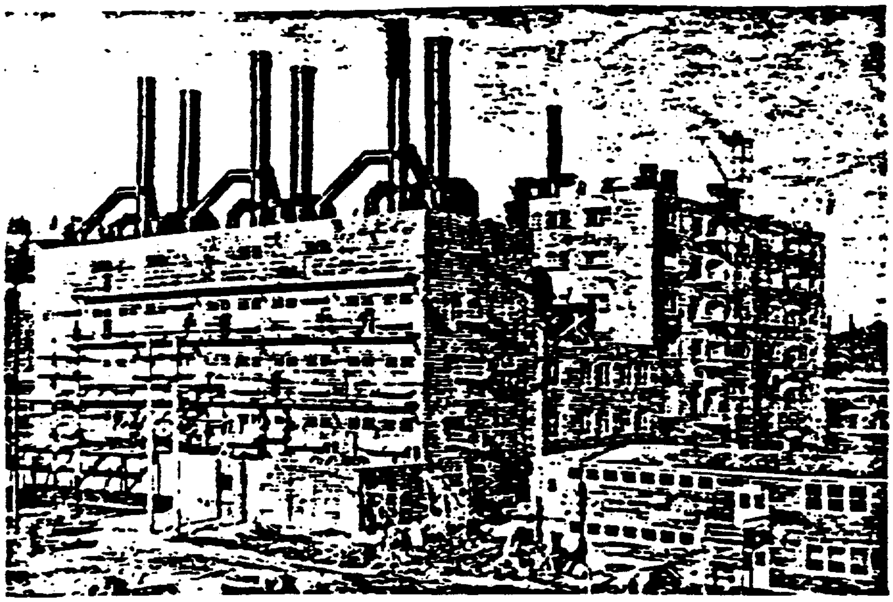
This article was prepared through the cooperative effort of several top men of Stone & Webster Engineering Corp.

T. R. Thornberg, project manager
T. W. Piper, personnel manager
R. R. Wisner, assist. project manager
T. J. Forde, contract manager
J. P. Piper, purchasing manager
G. P. Darlington, expediter
E. P. O'Connor, field accountant
H. I. Castlebrook, engineer



Chemistry building has tile enclosing walls and wood frame windows. Chicago boom on materials tower at right aided in bringing up equipment too large for handling inside the tower cage.

the work. Many thousands of drawings had to be provided so that the workmen in the field and in the factories could produce the component parts and subassemblies without gaining a clue as to the end product.

In spite of security restrictions and shortages of materials and manpower, there was completed within a three-year period a program for development and production that, in peacetime, would easily require 10 to 15 years. The urgency was so great that small scale laboratory developments were expanded directly into a gigantic production unit operated by personnel secured from all walks of life and with no previous similar training. Actually, the electromagnetic plant was the first unit to produce suitable quantities of the usuable product, and for nearly a year was the only plant in production.

Personnel was major problem

While the site of Clinton Engineer Works was still sparsely inhabited farmland a separate office of Stone & Webster was established in Boston for design, purchasing of material and equipment and expediting of delivery for some of the experimental works as well as for the major plants then contemplated. This and offices subsequently established at the Clinton Works and elsewhere were manned by a nucleus of experienced Stone & Webster employees.

By the time the project got under way, in November 1942, serious manpower shortages existed in all classifications so that the first step was to call conferences with representatives of labor organizations, the U. S. Employment Service, and the War Manpower Commission, at which scheduled requirements were discussed and the secrecy and urgency of the project outlined in enough detail to emphasize its importance.

WORK PERFORMED BY OR UNDER SUPERVISION OF STONE & WEBSTER ENGINEERING CORP.

General	
Excavation	7,200,000 cu. yd.
Roads	200 mi.
Sidewalks	225 mi.
Railroads	36 mi.
Sewer & water lines	550 mi.
Crushed stone	2,800,000 tons
Electric distrib. systems	160 mi.
Concrete	400,000 cu. yd.
Electromagnetic plant area	
Buildings	175
Floor area	4,500,000 sq. ft.
Cubic content	85,000,000 cu. ft.
Townsite and facilities	
Dwellings	7,843
Stores and misc. bldgs.	86
Dormitories, barracks	97
Hutments	1,325
Trailers	3,310
Warehouses	51
River pump house	28.0 mgd.
Filtration plant	15.75 mdg.
Sewage disposal plants	5.5 mgd.
Four reservoirs	10.5 mg.
Employment	
Av. of employees	18,000 per day
Peak of employees	28,000 per day
Manhours worked	105,000,000 hrs.

Recruiters were employed and stationed in the larger labor centers throughout the southeast. Those interviewed who met preliminary qualifications and were willing to accept a job were given transportation to the project for final inspection and classification. Each person employed was carefully investigated not only as to construction and technical experience but as to past history, loyalty, habits, citizenship and other characteristics, and each was required to sign a secrecy agreement. Requisitions for needed employees were submitted by each division superintendent and channeled through the project manager's office where an overall program was compiled and transmitted to the personnel manager for fulfilment.

Some idea of the magnitude of this undertaking can be obtained from the fact that in the period from Nov. 1942, the start of the project, to Sept. 1943, the number of persons employed by the Stone & Webster organization on the project increased to a peak of 28,000, and continued at that level for a period of eight months. The average number of employees up to the present time has been 18,000. To obtain this number, it was necessary to interview nearly 400,000 people, of whom about one out of three was hired.

Difficult living conditions

Like all construction jobs, mud, dust, and lack of housing made working and living conditions difficult at the start. Even greater effort was necessary to hold personnel than to get it.

In general, housing for construction workers was provided in several types of low-cost temporary units: (1) hutment camps, separated for white and colored and for laborers and craftsmen; (2) trailer camps, some utilizing government-owned units and some providing simply sanitary, lighting and road facilities for private trailer use; (3) small family huts for supervisors; (4) dormitories; and (5) a few houses in the townsite for department heads and administrative personnel.

Those employed to operate the atomic plants were given priority over construction workers on housing in the town site, and most of the latter had to commute from surrounding communities, a few from as much as 90 miles away.

Most of the work was done on a 10-hr. day-shift, but some second shift work was carried on to make greater use of heavy equipment and to bring special rush units up to schedule.

Naturally one would expect some labor unrest on a project of this magnitude and urgency. However, competent men in the Stone & Webster organization were in constant touch with union stewards, and were able to anticipate and compromise or arbitrate all grievances. It is estimated that not more than 10,000 man-hours were lost due to jurisdictional disputes or work stoppage, compared with the total of 105,000,000 man-hours worked.

PRINCIPAL CONSTRUCTION SUBCONTRACTORS
WORKING WITH STONE & WEBSTER ENGINEERING CORP.

Firm	Home Office	Class of Work
John A. Johnson Company	New York, N. Y.	Townsite housing
Clinton Home Builders	Charlotte, N. C.	Townsite housing
O'Driscoll & Grove, Inc.	New York, N. Y.	Townsite housing
Harrison Construction Co.	Pittsburgh, Pa.	Grading and drainage
Foster & Creighton Company	Nashville, Tenn.	Townsite buildings
Ralph Rogers Company	Nashville, Tenn.	Crushed stone
Transit-Mix Concrete Corp.	New York, N. Y.	Concrete
A. Farnell Blair	Decautur, Ga.	Townsite buildings
D. W. Winkleman	Syracuse, N. Y.	Water and sewer
C. O. Struse & Company	Philadelphia	Masonry
Rock City Construction Co.	Nashville, Tenn.	Townsite buildings
Fluor Corporation	San Francisco	Cooling towers
Bethlehem Steel Company	Bethlehem, Pa.	Structural steel
Watson-Flagg Engineering Co.	New York, N. Y.	Electrical Work
Hanley & Company	Chicago	Pipe & equip. instl.
Rockwood Sprinkler Co.	Worcester, Mass.	Sprinkler systems
Tennessee Roofing Company	Knoxville, Tenn.	Roofing
Bristol Steel & Iron Works	Bristol, Va.-Tenn.	Structural steel
Drainage Contractors, Inc.	Detroit, Mich.	Water and sewer
Sullivan, Long & Haggerty	Bessemer, Ala.	Water and sewer

Materials for the job

Purchasing $260,000,000 worth of major materials on a war-scarce market without telling vendors why items were needed in a rush was in itself no small feat. Secrecy was stressed at all times and the individuals working in this department and the manufacturers with whom orders were placed were completely unaware of the project's final object.

Stone and Webster's connection with the atomic bomb project antedates establishment of the Clinton Engineer Works with activities at first confined largely to securing raw materials. This included arrangements for the purification and transformation of uranium ore into the forms required for the several experimental processes underway and the procurement of other raw materials such as carbon and beryllium with purchasing handled from the Boston office. An early activity was the purchase of materials and equipment for the plutonium pilot plant constructed near Chicago.

Later, when Stone & Webster was authorized to proceed with construction of the electromagnetic plant and the town of Oak Ridge. the purchasing emphasis was transferred to materials and equipment for that major project.

A separate purchasing department was established in the Boston office to handle procurement of technical equipment and materials designed by the engineering department, and a contract office was maintained for preparation of contracts and subcontracts for process equipment.

A similar contract office was established at Oak Ridge to handle con struction contracts and subcontracts while a local purchasing department obtained construction equipment and materials. Coordination of purchasing activities was accomplished through the preparation of material schedules for each structure. The division of responsibility was made by the use of standard Stone & Webster forms listing the materials required and then assigning the responsibility for purchasing.

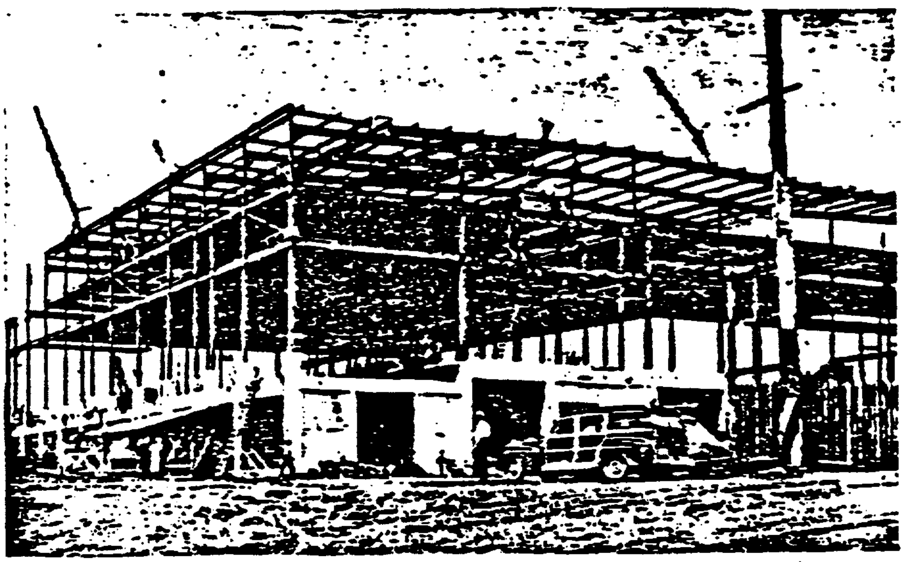
Contemplated extensions to the overall construction programs were known to executives and lists of steel, copper, alloy pipe, and other critical materials were prepared in advance of authorization to proceed with construction. These lists were forwarded to Washington and were discussed with War Production Board, with the result that orders for strategic materials invariably were placed within two days after authorization to proceed with construction. A considerable share of the credit for the excellent construction record is due to the unusually effective action of this procurement group.

In placing orders, full consideration always was given to the ability of manufacturers to make early deliveries. In certain instances, orders were intentionally divided among two or more vendors to obtain the advantage of the combined shop facilities. In general, orders were placed on an AA2X priority, which was sufficient to obtain most material and equipment. However, a liaison office of the Manhattan District in Washington, D. C. cleared rush matters with the War Production Board and, when necessary, arranged upratings to AAA, or directives to enable manufacturers to meet delivery dates.

Treasury annex

Procurement of equipment and materials for the project was handled through the media of contracts, subcontracts, purchase orders, and formal modifications thereto, involving a total commitment for the expenditure of $260,000,000. The largest individual purchase was a contract involving an expenditure of $17,500,000. Some 14,000 tons—$400,000,000 worth—of silver was borrowed from the U. S. Treasury for use as busbars and winding coils for the many magnets, taking the place of unavailable copper.

Thousands of vendors and manufacturers are numbered among the suppliers, and goods have come to Oak Ridge from nearly every state in the union. Awards for the secret process apparatus, however, were limited to a few producers, and each manufacturer was required to isolate the part of his plant used for the assembly. Purchase orders and subcontracts were made in the name of Stone & Webster Engineering Corp., while prime contracts were made in the name of the U. S. Government.



Concrete frames to second floor permitted start of building while steel was being fabricated. Designed for heavy load of electromagnetic process equipment the floor carries cranes setting the steel.

A force of 119 field inspector-expediters, 26 schedule men, 9 priority men and 85 field stenographers and clerks was utilized to inspect and keep material moving. The expediting office was located at Boston until April 1944 and since then has been at the project; in addition, branch offices were maintained in eleven principal manufacturing areas.

The job of the expediters was not to ask when needed equipment would be shipped. Instead, immediately after an order was placed, the manufacturer was contacted to determine that all information was at hand to start production. By following up suborders and material purchases using priority support, uprating of orders to AAA or directive and authorization of overtime, the quoted delivery dates of the manufacturer were accelerated in some cases as much as two or three months. At times, the inspection-expediting personnel had to find new sources of supply for hard-to-get items a prime contract holder required for manufacture. In some cases substitution could be arranged and frequently precious metals, loaned by the U. S. Treasury, were made available for use.

[illegible] per cent of the $260,000,-000 worth of material purchased required inspection prior to acceptance. This was handled by the inspection-expediting [illegible] the inspection-personnel [illegible] the same man [illegible]. In addition [illegible] organization. [illegible]

manufacture to meet speeded construction schedules and, fully as important, were in a position to advise that rush work on an item could be suspended in favor of some other rush job when the first could not immediately be used.

Handling the material

The receiving, warehousing and distribution of material and equipment necessary for the construction was a most difficult problem. Due to the scarcity of critical items and the unknown size of the ultimate development, it was considered essential that all material and equipment that might possibly be used be secured and kept on hand so as not to retard final completion.

Securing construction equipment was a major problem, met partly by obtaining over 5,000 pieces such as cranes, bulldozers, trucks, compressors and similar equipment from other government projects that either had been completed or closed down. In fact, Clinton Engineer Works became a central storage area for surplus materials of all types and description. As carloads arrived in unexpected numbers, the problem of distribution became a nightmare as the contents frequently were unsolicited and use for them unknown.

Much of the material received had to be stored in yards or in regional warehouses to be used when required, but a large portion could be checked at the central receiving station and then hauled to the planned point of use. A night crew was established for unloading and checking and, except for a very short period, no backlog of cars accumulated despite receiving 500 cars weekly of all kinds of material.

A systematized method of handling incoming material was developed for the process plant. At first, trucks transporting material and equipment from the central receiving depot went to an area receiving department where a man accompanied each truck to its ultimate destination and checked the material upon unloading.

As construction of warehouses progressed and railroads were brought into the areas, nearly all shipments were dispatched directly to the point of use or adjacent warehouses. In addition to general piping and electrical warehouses, a division warehouse was provided for each major process building and its appurtenant minor buildings. Subordinate warehouses were established within divisions for use of various departments. The vast quantity and variety of instruments required for the project, as well as their complexity made it necessary to provide separate warehouses for them.

Much "secret" equipment arrived in sealed cases, identifiable only by case number. Lists of equipment contained in the cases were secret and were not available to the material department. When a certain item of equipment was required, the number of the case containing the item was transmitted to the material department, and the case was brought directly to its destination. At no time was any secret equipment unpacked elsewhere than at the immediate place designated for its installation.

Concerted effort of many

Design of process and structures, the supplying of materials and the construction in the field for the electromagnetic plant, as well as other work on atomic bomb production handled by Stone & Webster was accomplished by the concerted effort of a much larger number of contributing firms and individual people th[illegible] can be listed here. On this projec[illegible] these subcontractors, materials suppliers and direct employees of Stone and Webster Engineering Corp. all over the country made outstanding contributions and all share, as they have served, in the achievement.

Process Buildings Over Faulted Rock

L. Kerr — Structural Engineer
P. Brown — Resident Engineer
Stone & Webster Engineering Corporation

● Faulted rock, found under an important building foundation, was utilized for support of heavy units of the electromagnetic process of separation of uranium isotopes by an unusually heavy foundation slab. For a later building on similar rock, basement space was obtained at no extra cost by excavating the entire building area to the top of the limestone, then pouring a thick base slab. Buildings are concrete or steel frame.

DIFFICULT FOUNDATION conditions were found to exist under some of the areas into which project expansion pushed the construction for the electromagnetic plant at Clinton Engineer Works. The plant, designed and built by Stone & Webster Engineering Corp., is located in a narrow valley with hills on each side to serve as protective barriers and isolate the process areas.

To expedite start of the project, layout and plans were made in Boston from aerial surveys, supplemented by some ground mapping of wooded areas. In general, these surveys were adequate but they were augmented as soon as locations of main buildings were known by comprehensive investigations made by core borings to determine conditions below the surface. These borings, and subsequent test pits and excavation for structures, disclosed that two fundamentally different classes of soil conditions existed in the valley.

On one side of a small drainage channel the underground formation is what is known as Conosauga shale. The top 2 to 5 ft. of the ground is medium to soft brown clay, resulting from the decomposition of the shale. Underlying this clay and extending for perhaps 5 ft., weathered shale in place is encountered.

This material contains clay seams, particularly in the upper portions, but the seams diminish rapidly in number and extent to a depth of not greater than 12 ft. The unweathered shale below that level forms an excellent and satisfactory foundation as it is virtually incompressible if protected from weathering during excavation and placing of concrete. Bearing conditions suitable for design loads of 12,000 psf. exist at depths of not more than 15 ft. and the structures planned

Limestone pinnacles and mud pockets were some of the difficulties encountered in foundations for the plant buildings.

Structures built in the early days of the project, when steel was especially critical, are all concrete frame. About 175 major structures were constructed by Stone & Webster for the electromagnetic process plant.

for this area were founded and built with no particular difficulty.

On the opposite side of the valley, however, soil conditions are entirely different. The underground formation. in general, consists of uptilted beds of dolomitic limestone of the Knox formation. These limestone beds are tilted away from the center of the valley at an angle of 55 deg. from the horizontal. Prehistoric streams eroded the uptilted beds into ridges running parallel to the strike between the limestone and the Conosauga shale. The crevices so formed vary in depth from a few inches to, in some places, 10 ft., and are filled with soft residual clays.

Boulders and pinnacles

In general, boulders of all sizes are found directly over or in the crevices of the limestone. Limestone pinnacles, ridges and boulders are encountered in the top 15 or 20 ft. of the ground surface. The shattered, uptilted beds of dolomitic limestone eroded by prehistoric streams and ground water that formed deep crevices in the limestone formation, together with boulders directly over the limestone surfaces, were most unsatisfactory for supporting heavy process buildings. As would be expected for a separation plant using giant magnets load concentrations are quite high, and permissible settlement is essentially zero.

The location of the first group of four main process buildings constructed was determined primarily to suit operating conditions and was over the shattered limestone. Coreboring holes made for subsurface investigation and supplemental holes to make a 15-ft. pattern each way were grouted in an attempt to fill cavities and crevices as well as to stabilize the limestone. About 1,100 cu. ft. of grout was pumped into 150 holes at pressures varying from 12 to 20 psi. The grout used varied in consistency from 3 to 6 gal. of water per bag of cement.

Over this grouted area, independent, soil-bearing, spread footings were adopted for the first three large buildings and, due to the restrictions on the use of steel, were of unreinforced concrete. A conservative bearing value, 15,000 psf., was used. Foundation conditions for the first process building did not offer any particular difficulties; the second and third buildings, although the conditions were much poorer, still could be constructed in accordance with the original designs.

Serious difficulty, however, was encountered in preparing the foundation for the fourth of the process buildings. When the overburden was removed, it was found that there was no solid rock as indicated by the core borings, but large, flat-topped and irregular boulders, some of which were 20 to 25 ft. in depth. These boulders, laid against and on top of each other, were usually so close together that the muck between could not be removed by mechanical means.

Heavy slab consolidates foundation

Here was real trouble, so serious that time and labor expended in attempting to excavate to suitable foundations only made conditions appear more hopeless. A new location was not logical from an economic or engineering standpoint. Construction of the other process buildings was well advanced, as well as that of a boiler house, chemistry group and other inter-related buildings. Therefore, after completing the general shovel excavation and hand cleaning, exposed limestone surfaces and crevices were given a thorough water flushing with fire hoses, and a solid mat of concrete was placed over a large portion of the building area. This mat was lapped over the ridges and large boulders in such a way as to tie the entire shattered limestone formation together.

Under the rest of the building, where underground conditions were not so bad, core holes were made and grouted as for the other process buildings. Unreinforced spread footings were constructed, resting directly on the mat that had been poured to hold

Thermal Diffusion Plant Built Rapidly

Original estimate for completion of design and construction was set at six months. The schedule was advanced by General Groves to four months, and actually the plant was delivered in 75 days.

Lt. Col. Mark C. Fox

Corps of Engineers, Clinton Engineer Works
Formerly in Charge of Construction and Operation, Thermal Diffusion Plant,
now, Chief of Construction and Engineering, Electromagnetic Plant

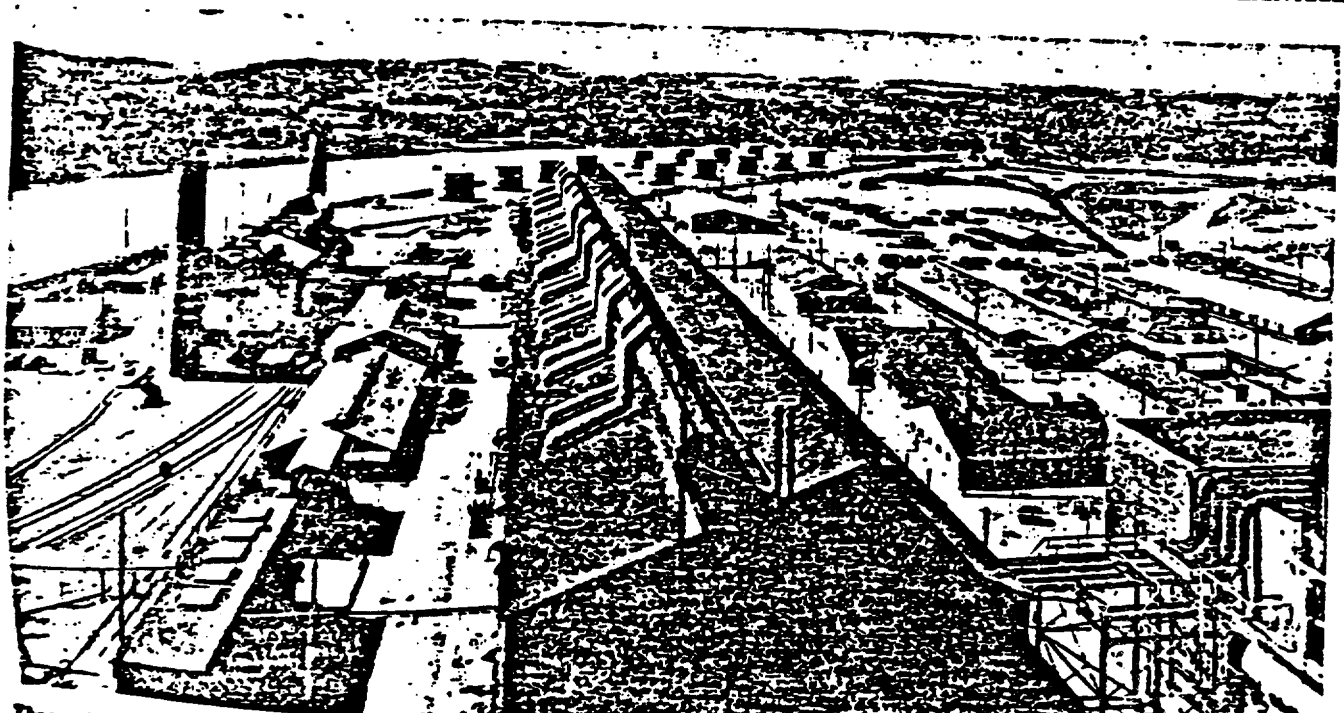
THE THERMAL diffusion plant at Clinton Engineer Works was designed and constructed within so short a schedule that the H. K. Ferguson Co. of Cleveland, which did the work, still do not exactly understand how they were able to do it. Even in a program where construction miracles were expected, this plant was spectacular.

General Groves decided to build this plant after P. H. Abelson, working for the Navy's research laboratory at Washington, proved that the thermal diffusion process was operable. This process involves a high heat transfer across a thin film of liquid or gas. If one side of this film is against a hot wall, and the other side against a cold wall, convection currents are established that cause upward flow along the hot wall and downward flow along the cold wall.

At the same time, due to diffusion, the lighter molecules of the gas or liquid tend to move toward the hot wall while the heavier molecules tend to move toward the cold wall. The two movements tend to concentrate the light molecules at the top of a column.

Dr. Abelson's columns consist of three concentric pipes, the inside pipe being a steam line. Saturated steam enters this pipe at the top and condenses as it flows toward the bottom. The latent heat in the steam provides process heat as the steam condenses. In the "annular ring" between this inside pipe and a second pipe is the material to be processed—uranium hexafluoride. Cooling water flows in a large annular ring between the outside of this second pipe and a 4-in. iron casing. The tremendous stresses established in bringing the column from room temperature to a condition where the outer pipe is cool while the inner pipe is hot required materials that could really "take it." In addition, uranium hexafluoride is one of the most corrosive chemical compounds known.

Each column acts as an individual



Thermal diffusion plant as viewed from roof of main steampower plant. Pipe connections at right are to high-pressure steam source. The auxiliary steam plant at left utilizes twelve oil-fired marine boilers—surplus when the destroyer-escort program was curtailed—to supply process steam.

unit, although a group of columns usually are operated in parallel. As described above, the condensing steam transmits heat through the film of liquid or gaseous uranium compound. The inner wall is hot and the outer wall is relatively cold. U-235 molecules diffuse toward the hot wall and are carried upward by currents of convection. Uranium compound enriched in the 235 isotope is then skimmed off at the top while the depleted uranium compound is taken off at the bottom. This process works most efficiently when providing only a slightly enriched product.

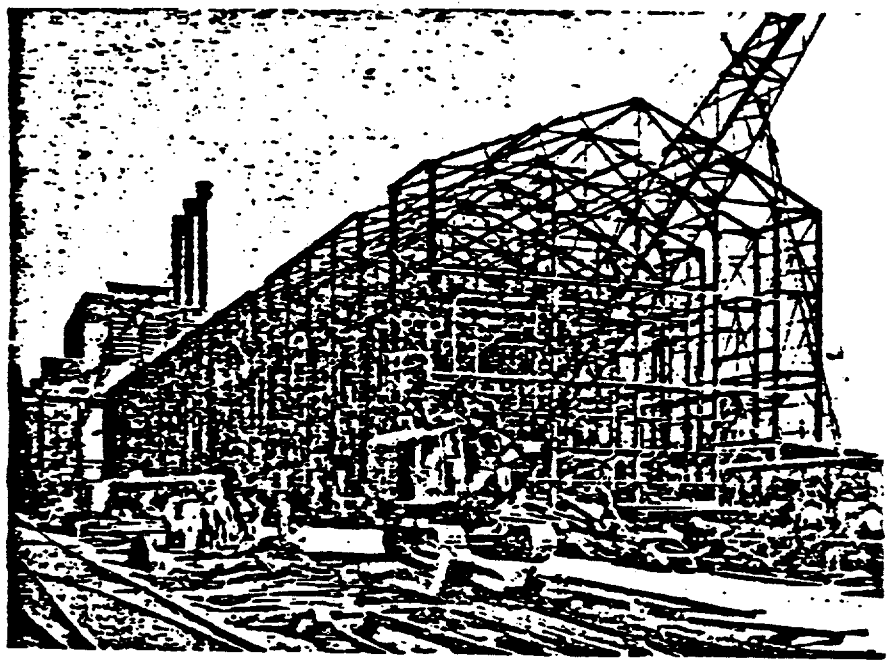
The electromagnetic plant was the only one in operation for nearly a year and there was a great desire to increase its production rate. This could best be done by increasing the percentage of U-235 in the feed material. Natural uranium has a concentration of 0.7 percent of pure U-235. If this concentration could be doubled in the feed material to the electromagnetic units their output could be correspondingly increased. Dr. Abelson had enriched considerable quantities of uranium to a 1.4-percent concentration of U-235 in his small plant at Washington and it appeared that a larger plant could be built quickly, using steam from the existing power plant for heat.

Built "right now"

On June 26, 1944, General Groves instructed the H. K. Ferguson Co. to proceed with the design and construction of the plant. The Ferguson company estimated that the plant could be designed and built in six months, providing top priority would be given it; so General Groves instructed that it be completed in four months. He later revised this schedule to three months, and actually, the plant was in operation in 75 days.

The main building is 525x82 ft. and 75 ft. high. It is a semi-standard design developed by Ferguson for which detail drawings were ready. A structural steel take-off was made on July 2nd. The WPB granted a Class 5 directive on July 3rd, and the steel was rolled on July 4th. Ground was broken on July 13th, and the first producing unit was processed for operation 66 days later.

The Ferguson company did the general construction and sublet the specialist work. Erection of the 2,000 tons of steel, for example, was done with their own forces, some 90 percent of it being set directly from the delivery cars without rehandling. Subcontractors on the job included the Edenfield Electrical Co., for electrical installations; Turner & Ross Co., Pittsburgh Pipe and Equipment Co. and the National Valve Co. on piping installations; the Tri-State Asbestos Co. for all insulation work and the Tennessee Roofing Co. for sheet metal installations. Pumps were furnished by Pacific Pump Co. with motors by Westinghouse. Mehring & Hanson Co. and the Grinnell Corp. furnished the process columns—after 23 major manufacturers separately agreed it was not possible to make the columns on a production basis.



This 525-ft. long building, filled with pipe, pumps and valves constitutes the thermal diffusion plant for which process steam was supplied by power plant.

Big pumping job

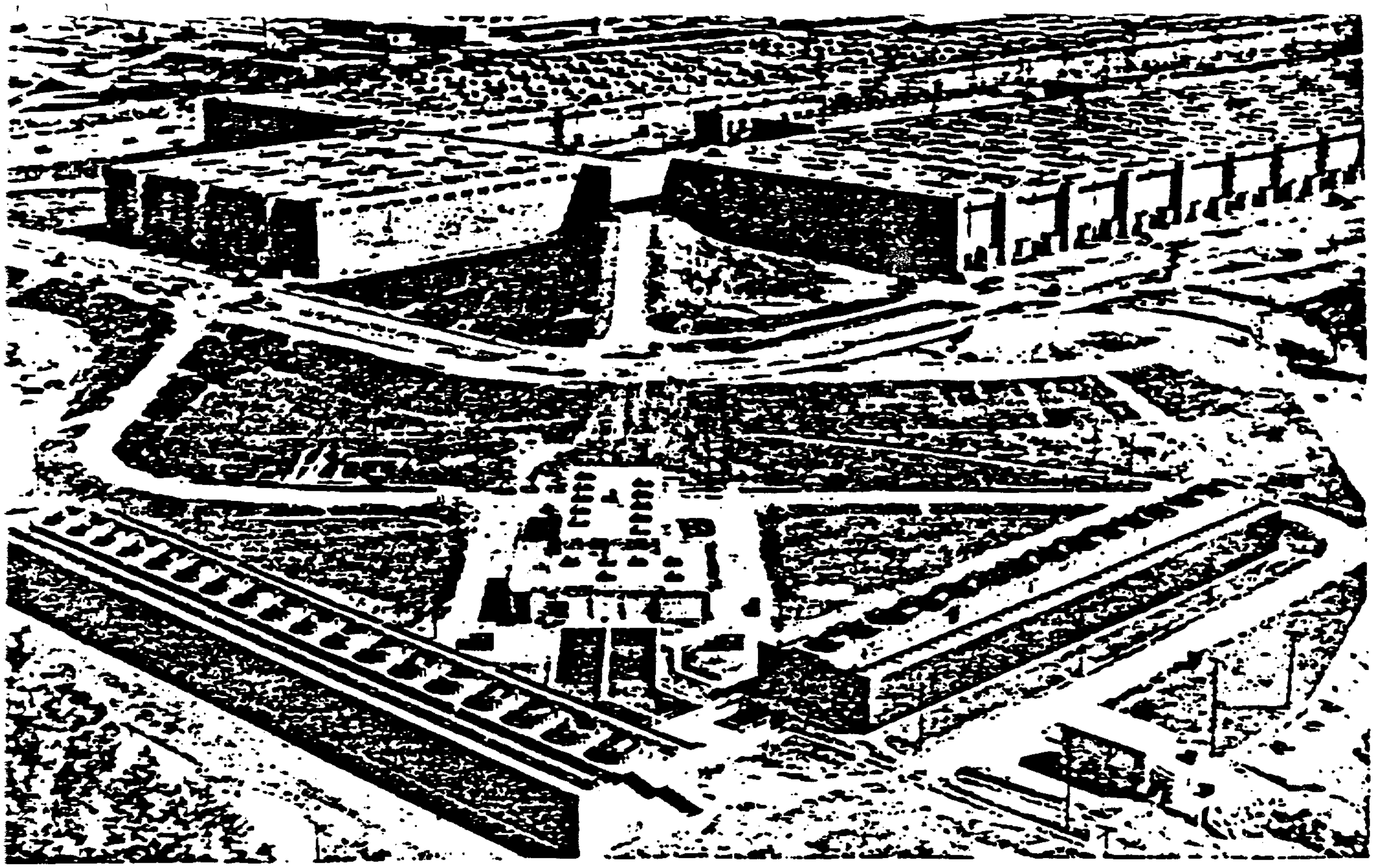
Equipment installed included 42 centrifugal pumps of 10,000-gpm. capacity driven by 100-hp. motors and four 15,000-gpm. vertical turbine pumps with 700-hp. motors, almost 15,000 valves, varying in size from ½ in. to 54 in. and from low pressure water to high pressure steam, and 50 miles of nickel tubing.

The plant was located adjacent to the main steam power plant of the Clinton Engineer Works for easy transfer of heat. But high pressure, superheated dry steam, while essential for power purposes, is not an efficient heating medium as it does not readily give up its heat. Consequently, it has been necessary to saturate the steam, which has been done by pumping "return water" directly into the 1,250-psi. at 900-deg. F. steam line, an expedient never before accomplished. Introduction of water from the hot condensate return line increased the volume of the steam while reducing both its pressure and temperature.

The Pacific Pump Co. adapted a pump, which they had been using to pump hot oil in Persia, to the job and three of these elaborate contraptions, known as "silver queens," were built and installed on time.

The Corps of Engineers personnel, under the author, included Maj. R. F. Looney, and Capt. Harry Burton on procurement and expediting, Maj. Thomas J. Evans, Jr., in charge of construction, and Capt. Van S. Reid, executive officer. H. K. Ferguson Co. was represented by W. N. Thompson, chief engineer, Frank Buck, chief mechanical engineer, W. K. Mitchell, general manager, C. W. Roberts, project manager, George Lindquist, general superintendent, and G. R. Byrd, mechanical superintendent.

As construction neared completion, the Ferguson firm formed a wholly-owned subsidiary, The Fercleve Corp., to operate the plant. Long before the construction forces moved out, the operators moved in, conditioned the columns and the piping and started to operate the plant.



Cooling towers and flumes in foreground handle a large volume of water, which is pumped to the huge process building.

Largest of the Atom-Bomb Plants

John F. Hogerton
Job Engineer, Kellex Corp., New York

● *The gaseous diffusion plant is one of the largest and most complex plants in industrial history. It has to be big to accommodate the enormous amounts of gas that must be recycled thousands of times to extract usable concentrations of U-235. A number of auxiliary systems are required, some of them sizeable plants in themselves. Two unusual features of the process systems are the unbelieveable cleanliness of everything connected with the plant, and the unprecedented vacuum tightness of the equipment.*

LARGEST OF THE GREAT plants for production of material for the atomic bomb is that for the gaseous diffusion method, which exists as a massive array of buildings in a large area at Clinton Engineer Works. The plant and appurtenances were designed and engineered by The Kellex Corp., organized for this project as a subsidiary of M. W. Kellogg Co., New York. Planning alone required 20,000 pages of specifications, 12,000 drawings and 10,000 pages of operating instructions.

Principal structure of the plant, and perhaps the most impressive of all those built in connection with the atomic bomb project, consists of a huge U-shaped installation, which contains the diffusion cascade and related process equipment. Four stories high, over a half-mile long and nearly a quarter-mile across, the structures cover an area of 60 acres. The interior of the U is at the level of the first floor while the outside is at the basement level. The buildings are of reinforced concrete to the main floor level, with steel frame and asbestos-cement siding from there to the roof.

The first level is occupied by auxiliary equipment—transformers, electrical switch gear, ventilating fans and duct works. The second and main level accommodates the diffusion stages, which are completely enclosed by welded steel panels. The third level is a pipe gallery, which carries the main process headers as well as a variety of auxiliary pipelines. The process headers, like the stages, are enclosed by steel panels. A volume of 6,000,000 cu. ft. is so enclosed and a "special atmosphere" maintained inside.

The fourth level is the operating floor. Here are installed the hundreds of instrument panel boards and control devices for operating the diffusion cascade. In a central location on the operating floor is a master control room, equipped with instruments that make it possible to scan the operations over the entire cascade. From this central station one can set in motion robot controls for isolating sections of the cascade from the main process stream.

But what is a cascade and why is such a large plant required for production of small amounts of the finished product?

How diffusion works

As the name gaseous diffusion implies, the fissionable U-235 is separated from inert U-238 (with which it is found in nature in a ratio of 1 to 140) while it is in a gaseous state. The heart of this process is a highly specialized type of porous membrane, known as a "barrier" that contains hundreds of millions of pores per square inch. These pores are submicroscopic—their average diameter is estimated at two millionths of an inch. To understand how the diffusion process works, picture a barrier dividing a chamber into a high and a low pressure zone. If a mixture of light and heavy gases is pumped through the high pressure zone, the fraction that passes or "diffuses" through the barrier into the low pressure zone will be found to be appreciably richer in the lighter component of the mixture.

The extent to which any two gases can thus be separated in a single stage has been found to be proportional to the square root of the ratio of molecular weight of the gas molecules. One, if not the only, gaseous compound of uranium is uranium hexafluoride. With hexafluoride the U-235 has a molecular weight of 349, and U-238 a weight of 352 so that the theoretical separation factor is only 1.0043. Thus many hundreds of stages are necessary to obtain a very high concentration of U-235. In actual practice imperfect barriers and operating conditions necessitate even more than the theoretical number of stages required. The plant at Clinton Engineer Works actually contains several thousand diffusion stages and enough barrier to stretch from New York to Tokyo! Such a combination of stages is known as a cascade.

Several thousand stages require thousands of diffusers, thousands of pumps, thousands of heat exchangers, thousands of valves, thousands of instruments and miles and miles of pipe —all connected into one continuous system. Hence, the great plant.

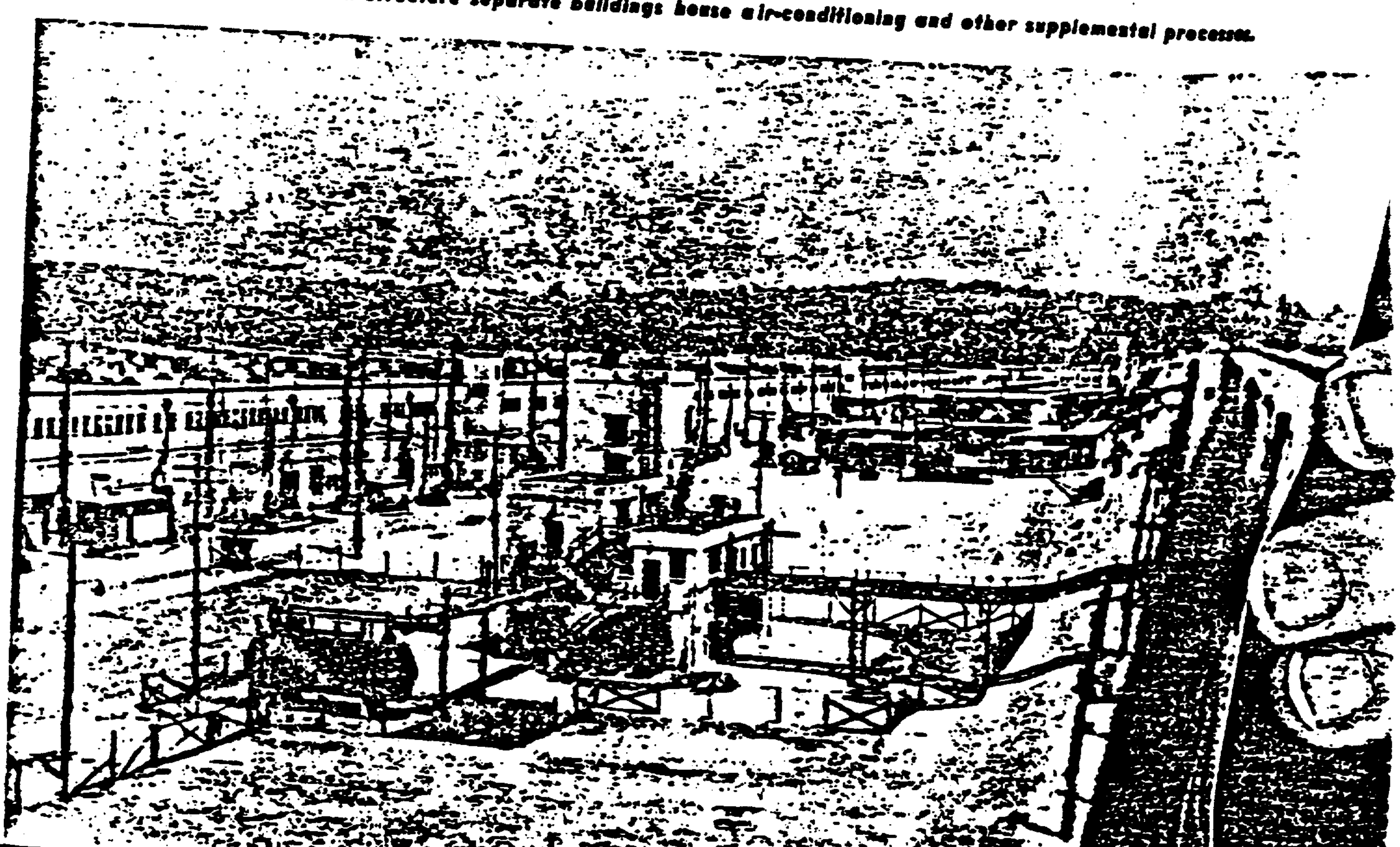
But the number of equipment units and the complexity of the system are only part of the story. Added to this is the fact that a cascade processing the uranium hexafluoride must be operated at reduced pressures and hence all process equipment must be vacuum tight. Further uranium hexafluoride is one of the most corrosive chemicals known, attacking practically all metals, non-metals, organics, and even water with equal relish. The problem is further complicated by the fact that even at reduced pressure uranium hexafluoride solidifies at around 100 deg. F.

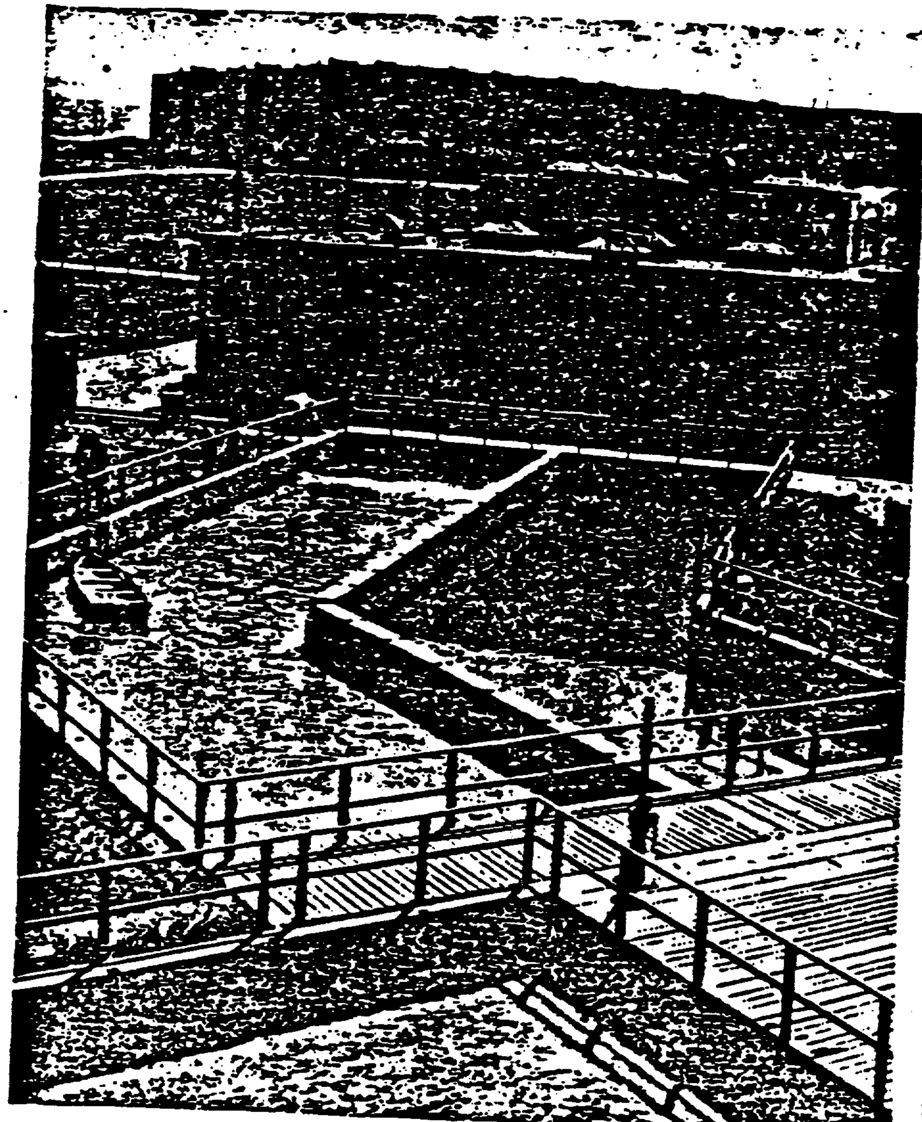
Although the principle of gaseous diffusion was known as far back as 1829, this plant represents its first application outside the laboratory. Heretofore the materials to be separated have always had sufficiently dissimilar physical or chemical properties to permit the use of better known methods such as distillation, absorption, crystallization, or the like. The isotopes of uranium are such nearly perfect twins, however, that methods comparable to gaseous diffusion had to be developed for this separation.

Auxiliary System important

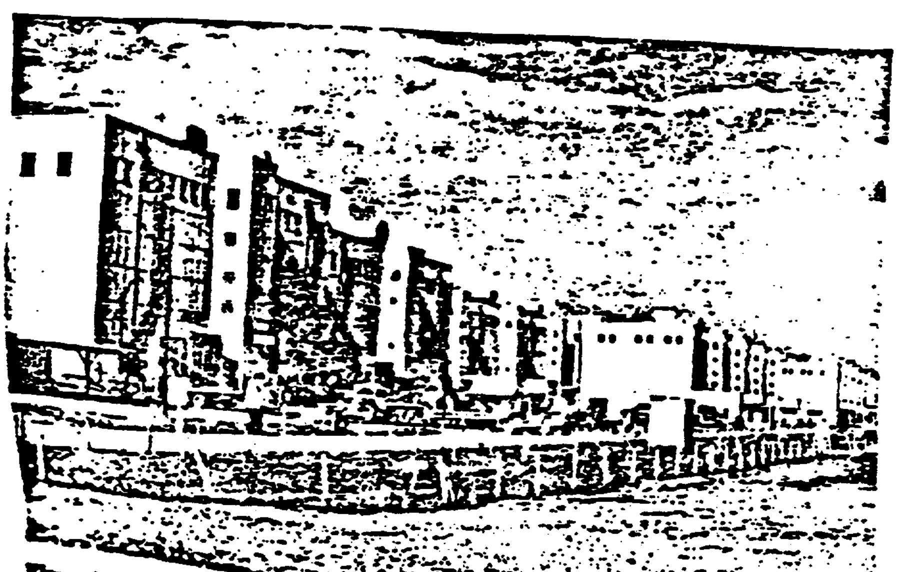
There are many auxiliary systems connected with the diffusion cascade plant that are of special interest. Located in the center of the U are a number of unusual plants, one of which is the largest air-drying installation ever built. Nearby, but outside the U, is one of the largest spray cool-

Inside the U of the main structure separate buildings house air-conditioning and other supplemental processes.





Large volumes of water are circulated for the gaseous process. These flumes connect to the cooling towers.



Viewed from any angle the gaseous diffusion plant is impressive, with acres of [illegible] exterior walls.

ing tower installations ever made, part of a recirculating cooling water system that handles enough water to supply a city of 5,000,000.

There are many other interrelated parts of the plant—a "conditioning" area that is a large-scale plant in itself, laboratories where temperatures are maintained within two-tenths of a degree, offices, cafeterias, a hundred warehouses, bus terminals, garages, and miles of roads and railroads that normally go with the very largest industrial plants. Power for the process is supplied by a 238,000-kw. steam-generating plant, the largest single initial installation ever made.

Built by contractors

Such is the gaseous diffusion plant, built in its entirety on an undeveloped and remote site in barely two years time! This miraculous construction task was accomplished by the J. A. Jones Construction Co. Inc. and by Ford, Bacon & Davis, Inc., management contractors, with the Kellex Corp. acting as supervisor of construction. The plant is operated by Carbide and Carbon Chemicals Corp. The Jones Co. built the process plant, the administration area, power plant and yard facilities, while Ford, Bacon & Davis had the responsibility for the conditioning area. In addition, the two firms built labor camps to accommodate 12,000 men.

There are two terms that neither the Jones organization nor Ford, Bacon & Davis are likely ever to forget. One is cleanliness control and the other vacuum tightness. The former meant that the entire process plant had to be as clean as a surgeon's forceps and the latter that the plant had to be as vacuum tight as a thermos bottle.

Cleanliness of first importance

As an illustration of cleanliness a thumb print represented contamination in the gaseous diffusion plant *sense of the word!* All process equipment from individual valves to subassemblies of pipes had to be put through as many as a dozen cleaning operations, including sandblasting, degreasing, alkaline cleaning, acid pickling, and surface passivation. After cleaning, equipment was dried and then tightly capped to prevent contamination during handling. Certain equipment items were pressured with dry nitrogen to preclude any possibility of moisture infiltration.

Once cleaned, dried and capped, the equipment was subject to the procedure known as cleanliness control. The first step here was to partition off the building in which the equipment was to be installed and thoroughly clean it from roof to basement. Not only was all construction debris cleared away but all building surfaces, even the ceilings, were wiped down by hand or vacuum cleaned.

Once the building was cleaned, elaborate precautions were taken to keep it that way. For example, the building was placed under forced draft ventilation and all air was filtered; only essential trucks were permitted to enter the building and these were hosed down; workers were admitted only after they had brushed their clothing. This cleanliness control program is thought to be one of the most unique activities ever encountered on a construction project.

Vacuum tightness presented entirely different problems. Here it was necessary to develop more than a dozen welding techniques as well as techniques for locating and repairing the most minute leaks. As many as 1,200 welding machines were in use at one time with both pressure and vacuum testing brought into play in testing the installation. The former was used for locating gross leaks and the latter for locating small leaks and measuring final tightness.

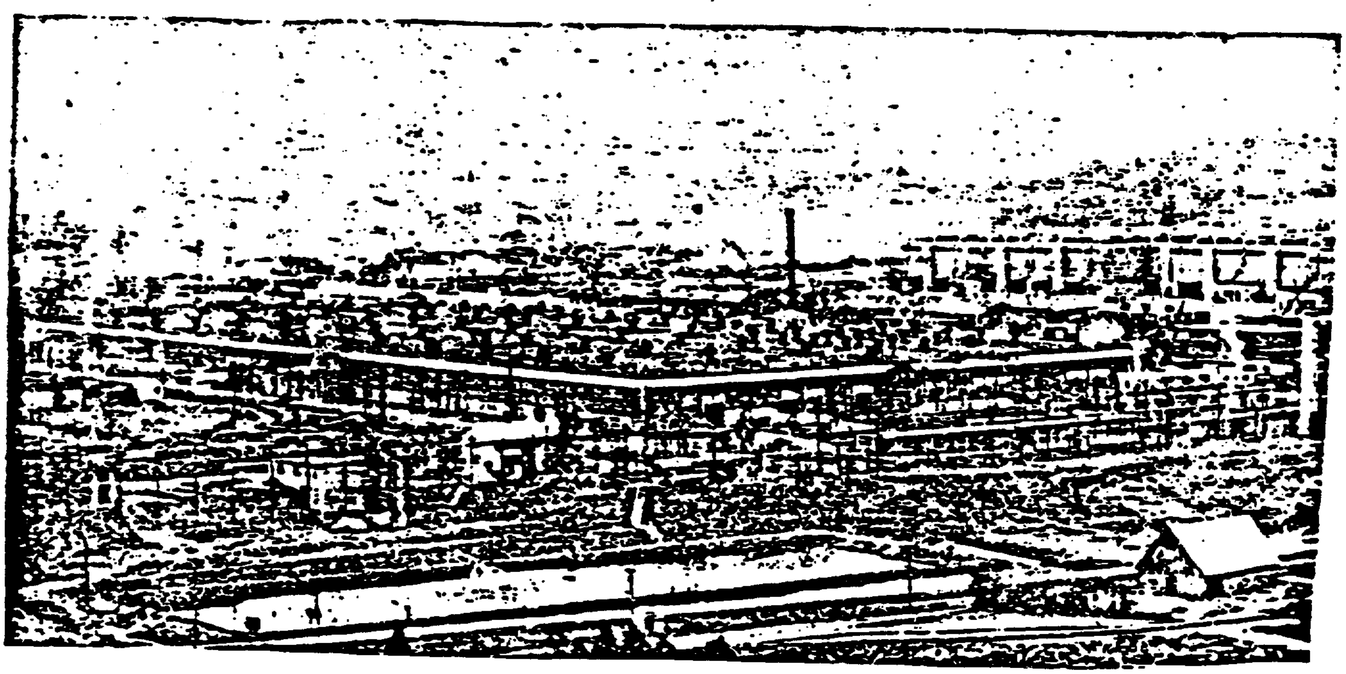
In the vacuum method the unit under test is continuously evacuated by a high speed pump, while suspected areas are probed with a special gas. Traces of the probing gas in the exhaust gases indicate leakage.

Welding by the mile

Other unusual construction problems encountered in building the gaseous diffusion plant were the erection of air-tight stage enclosures, which involved nearly 1,000 miles of air-tight welding and which engaged as many as 400 sheet-metal workers at one time; the installation of 3,800 miles of electrical conductors and 825 miles of electrical conduit, involving more than 90,000 separate tests on electrical systems; and the installation of thousands of precision instruments requiring 4,000,000 ft. of copper tubing and 3,000,000 ft. of copper wire.

On the structural side is the fact that the U and related structures were built on compacted fill, a method that up until then had not been extensively used in building construction. A separate article describing this work appears on page 144. Another structural feat, described on page 141, was unprecedently rapid planning and construction of the power plant requiring less than a year from inception of the idea until power was delivered.

Activities of the Kellex Corp. at Clinton Engineer Works was directed by P. C. Keith, vice president; A. L. Baker, project manager; and A. A. Nickman, resident engineer.



Essential Unit of Gaseous Plant Constructed by Ford, Bacon & Davis

"Conditioning" plant in foreground was designed and built, and for a time operated, by Ford, Bacon & Davis, Inc. for part of gaseous diffusion process. Work carried on in the structure includes preassembly of process equipment into large units and cleaning of process parts prior to installation.

Flexibility was a prime consideration in designing the 400x1,000-ft. one-story and part basement steel-frame structure, which has walls largely of sash. Interior bays are 40x40 ft. throughout the building, with only temporary partitions provided so that alterations can be made as necessary to meet constant changes in the plant.

An example of built-in flexibility is found in the means for meeting varying demands for power throughout the structure. Unit substations, each including a large power transformer and associated switching equipment within a single housing, are located at convenient points outside the wall. As changes occurred in the power demand, the substations were shifted or units added to keep the length of low tension leads and the amount of line-loss to a minimum.

For Ford, Bacon & Davis, Inc., Carl A. Schneider was in charge of design, done in the New York Office. C. C. Whittlesey was project manager on construction of the conditioning building and other related structures.

Organization Set-up For $5,000,000 a Month Payroll

Edwin L. Jones
General Manager, J. A. Jones Construction Co. Inc.
Charlotte, North Carolina

● **The Jones organization was set up in six major divisions to handle construction totaling $300,000,000 at Clinton Engineer Works. Activities on the main gaseous diffusion plant were directed by a project manager with authority delegated through superintendents for each craft and even further to the supervisor on a group of several building units. Subcontractors are given a large share of the credit for the accomplishment.**

SIZE OF PAYROLL is not a good criterion of work accomplished but under existing security restrictions it is perhaps the best means of picturing the size of the job done by J. A. Jones Construction Co. in building the gaseous diffusion plant at Clinton Engineer Works. On a sparsely inhabited rural area in Tennessee a construction force was built up in a few months to a sustained payroll of $5,000,000 a month with weekly peaks in excess of $2,000,000. The total cost of work on the one area at Clinton that was handled by this firm will exceed $500,000,000 including purchase price and installation costs of process equipment.

The Jones organization moved into one corner of the 59,000 acre government reservation in May, 1943, with a contract to build a steam power plant, which was the largest initial installation of this type ever made. In September, they were authorized to build the gaseous diffusion plant in the least possible time. It was necessary to build a camp to accommodate 12,000 construction workers, as well as to provide roads, bridges, a railroad, bus terminals, and huge parking lots accessible to the working area.

Later, to meet increased demands for heat, three additional steam plants were erected. And finally, an addition to the diffusion plant was built, to greatly increase the amount of material processed.

Due to the unremitting pressure for completion of the project at the earliest possible date, work was carried on seven days a week, 10 hr. a day, Monday through Friday, and 8 hr. on Saturday and Sunday, to make a work week of 66 hr., for which most employees were paid for 79 hr. of work. Sunday work was discontinued early this year.

PRINCIPALS IN J. A. JONES ORGANIZATION

General Manager
Edwin L. Jones

Power Plant and Utilities
J. E. Davidson, Project Manager
W. H. WcWhirter, Gen. Supt.
John D. Watson, Chief Engineer

Main Process Plant
H. V. Appen, Project Manager
J. C. Douche, Asst. Project Manager
A. C. Samford, Gen. Superintendent

Administration
A. V. Junkin, Manager
O. E. Breuggeman, Engineer, Contract and Claims
A. G. Underwood, Supt. Personnel

Materials Control
T. F. McVeigh, Gen. Superintendent
M. E. Ober, Procurement
L. R. Cornish, Receiving & Warehsg.

Inspection
A. L. Crawford

Safety
D. N. Kelly

The principal difficulty in organizing the job was caused by the fact that each unit had to be built "all at one time." As soon as plans were partially ready a schedule for completion was established, and lagging behind was not tolerated. In some few instances such speed was perhaps not justified, but no one knew in what part of the plant delaying difficulties might occur, so every phase of construction was carried on at top speed.

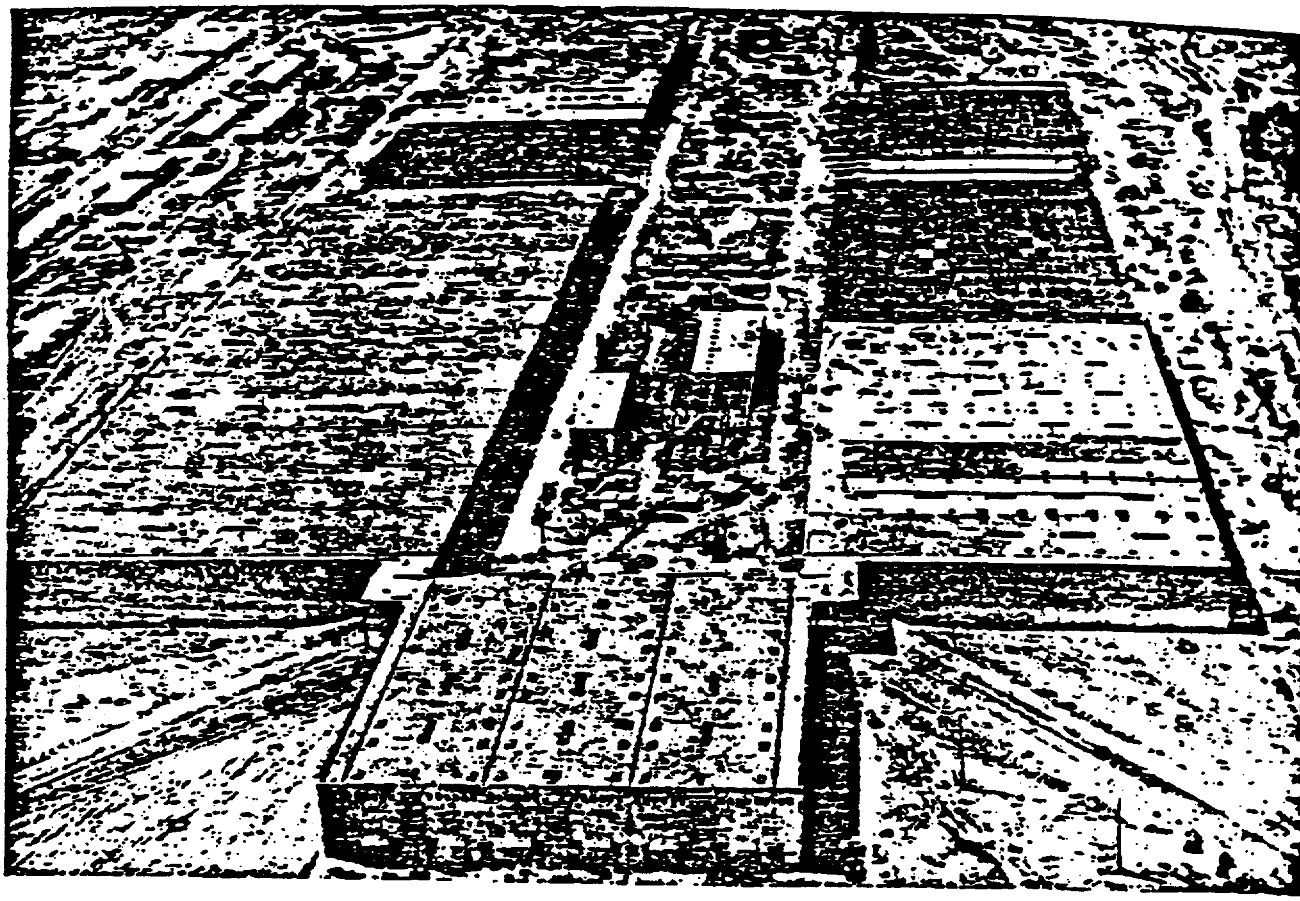
This meant that the closest control had to be maintained over the flow of material, field coordination between all trades, engineering planning and design, installation of production equipment, and finally the testing and pre-operational runs. There was no "leeway" in the construction schedules, and speed had to be maintained without any excuses.

Departments under a single head

Despite the close coordination required, definite separation of the work into functions and areas proved to be very successful.

There were six major divisions of the company's organization that reported directly to the general manager. Construction accounted for two of the divisions, each of which was run independently by a project manager. Each unit was assigned a substantial portion of the work and separated from other units by an easily defined natural boundary.

Administrative functions were kept entirely separate from that of construction and engineering, so as to leave those groups free for their special jobs. An administrative division, operating under its own manager had full charge of personnel,



Main structure for the gaseous diffusion plant is in "U" shape 2,500 ft. on a side by 400 ft. wide and made up of several connected "buildings" housing the many thousands of "cascades" used in the separation process.

timekeeping and payroll, plant security, contracts and claims as well as plant service. This division handled the recruiting of labor, timekeeping and payrolls for the three fixed-fee sub-constractors as well as for the general contractors.

The materials control division had full charge of all purchases, priorities, procurement and expediting of materials and supplies as well as the receipt, warehousing and distribution of all items. This division did all auditing and was responsible for the payment and reimbursement of all bills for the general contractor and for the fixed-fee subcontractors.

An extremely high standard of perfection for the installation of all the process piping and equipment was established, and to the general contractor was given the responsibility for seeing that these specifications were carried out to the letter. To accomplish this an inspection division was set up and divided into sections with an experienced engineer in charge of each section such as structural, electrical, mechanical, instrumentation, and the like. The safety department also reported directly to the general manager.

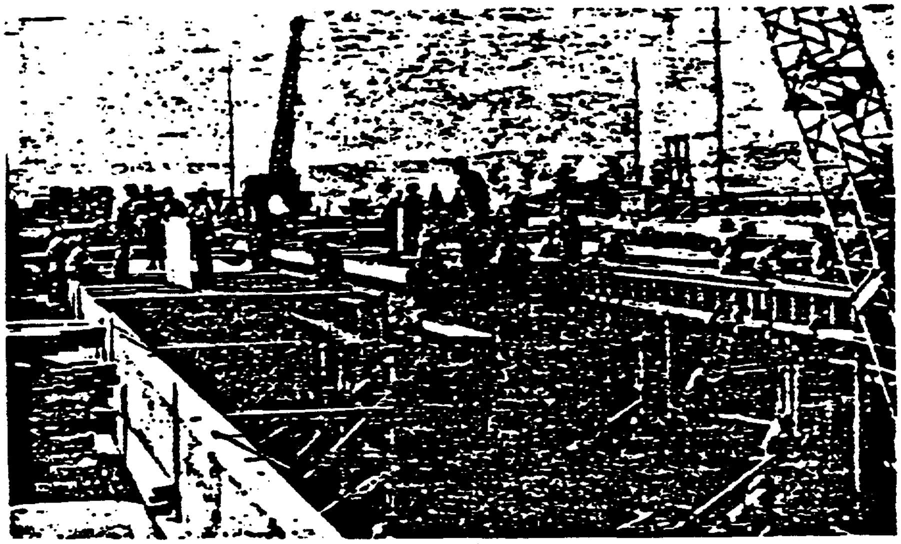
Construction plant design

The general contractor maintained a design engineering department in the field to prepare plans for temporary construction and camp buildings, including such unusual construction facilities as a bowling alley, an ice plant, village stores, and a locomotive repair shop. This department also designed the permanent water treatment plant, a large part of the

PRINCIPAL STRUCTURAL SUBCONTRACTORS ON GASEOUS DIFFUSION PLANT

(Exclusive of power house)

Firm	Home Office	Work performed
D. W. Winkleman	Syracuse, N. Y.	Railroad and site grading
Oman Creighton Co.	Nashville, Tenn.	Site grading
Wolfe-Michael Const. Co.	St. Augustine, Fla.	Site grading
Bethlehem Steel Co.	Bethlehem, Pa.	Fabricate and erect steel
Virginia Bridge Co.	Roanoke, Va.	Fabricate structural steel
Lambert Brother	Knoxville, Tenn.	Concrete aggregate
Birmingham Slag Co.	Birmingham, Ala.	Concrete aggregate
Cooney Brothers	Tarrytown, N. Y.	Mix and deliver concrete
H. E. Anning Co.	Chicago, Ill.	Poured in place gypsum roof
L. K. Comstock	New York, N. Y.	Process plant electrical installation
Bryant Electric Co.	High Point, N. C.	Process plant electrical installation
Midwest Piping & Supply Co.	St. Louis, Mo.	Process area piping
Poe Piping & Heating Co.	Greenville, S. C.	Process area piping
G. G. Ray & Co.	Charlotte, N. C.	Roofing and sheet metal
Kerby-Saunders Inc.	New York, N. Y.	Sheet metal and [illegible]
Ce-Mas-Co Floor Co.	Chicago, Ill.	Asphalt mastic floor



Forms for the floor of the gaseous diffusion process building were largely prefabricated. Concrete was placed by pumping throughout the building.

water distribution and the sewerage systems and the sewage treatment plant. Plans and specifications were prepared for two major bridges as well as for 25 miles of primary access roads.

Each a big job in itself

A few figures give some idea of the magnitude of the work involved and show why the contractors organization had to be flexible and departmentalized so as to secure specialization, and yet so integrated as to have a minimum of friction or lost motion. For the two main process plants described above 2,500.000 cu. yd. of excavation were handled; 500,000 cu. yd. of compacted fill were placed. under laboratory control: 450.000 cu. yd. of concrete was placed; 14,000 tons of reinforcing steel was installed and 40,000 tons of structural steel erected.

In the main process plant area the principal structure is the gaseous diffusion process building. This is a "U"-shaped structure 2.450 ft. long, and 400 ft. wide on each side, with a floor area of 5.560.000 sq. ft., making it one of the largest connected industrial buildings. It has a concrete basement, with concrete frame and slab for the first floor, and steel framing for the second and third stories. This design served the purpose of saving steel and also permitted a rapid start of construction while the structural steel for the upper parts of the buildings was being rolled, detailed, fabricated and delivered.

Concrete was delivered in mixer-trucks and pumped to the footings, columns, and floor slabs. Steel was erected by conventional cranes. Asbestos-cement sheets were substituted for brick on the outside walls to reduce the amount of on-site labor required.

A general superintendent directed 9,000 to 15.000 employees on the main building and on immediately tributary work. Under the general superintendent was a superintendent for each of the several classes of work, and also a building superintendent for each of the several types of structures. The various building units within the main structure were divided into groups of three to six, depending somewhat on the ability of the building superintendent and the urgency of the requirement for the particular structures.

Coordination of all phases of the plant construction was one of the most difficult things that the management of the general contractor had to solve on this project. Since construction kept pace with the design work there was little opportunity for advance planning or scheduling. This difficulty was met by a general coordination meeting of the prime contractor with the subcontractors and the designing engineers and, fully as important, by regularly scheduled meetings at least weekly with departmental engineers and superintendents for each of the major subdivisions of the construction program.

JONES AND FIXED-FEE SUBCONTRACTORS FORCE DISTRIBUTION
(Largest week, May 12, 1945)

Classification	Employees
Laborers & tenders	2,753
Carpenters	2,439
Cement finishers	84
Electricians	2,644
Ironworkers	859
Painters	175
Plumbers, steamfitters	5,472
Sheet metal workers	1,059
Boilermakers	355
Bricklayers	43
Firemen & oilers	326
Mechanics	389
Machinists	423
Equipment operators	406
Truck drivers	736
Other crafts	492
Craft foremen	1,901
Manual	20,556
Non-manual	4,229
TOTAL	24,785

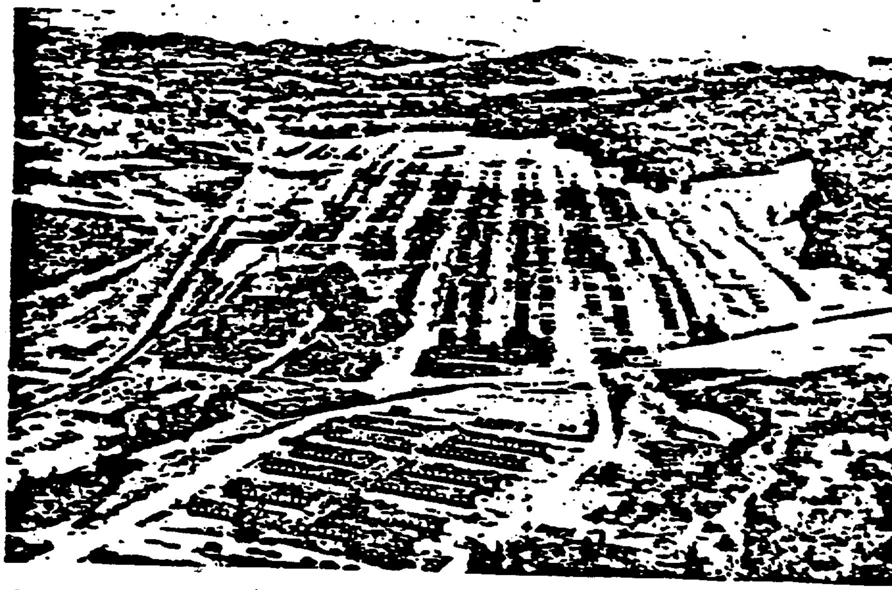
Subcontractors play big part

Equipment was installed by the general contractors own forces, handled as a part of the work under the project manager and the general superintendent of mechanical erection. Process piping and controls, however, were installed by subcontractors and credit for the speed and success of the installations goes in large measure to the experienced firms who undertook to do the work on such exceptionally rapid schedules.

Piping, electrical and instrumentation installations had to be coordinated and space provided for all of the intricate maze of installed equipment that is essential to the process. This required a tremendous amount of work by millwrights and boiler makers, and was accomplished rapidly despite some necessary changes, by cooperation of all from designers to craftsmen.

Process gas piping was fabricated and installed by the Midwest Piping and Supply Co. of St. Louis, Mo. All other piping—including water, steam, air, gas vent, and refrigeration—was installed by the Poe Piping and Heating Co. of Greenville, S. C. The electrical work was installed by the L. K. Comstock Co. of New York and the Bryant Electric Co. of High Point, N. C., operating as co-venturers. These three subcontracts were awarded on the basis of cost-plus-a-fixed-fee and, about sixty unit price subcontracts were let for specialized features of the work.

To house and feed 12.000 construction workers on the gaseous diffusion plant area, a separate unit for camp operations was set up under a superintendent. Prefabricated huts were erected first to provide immediate housing. Later, many dormitories, each accommodating 132 men in double rooms, were built. Nine hundred government-owned trailers were moved in to house families. Parking space and adequate sanitary facilities were installed for privately owned trailers. Stores and recreational facilities were provided for the camp.



A trailer, dormitory and hut camp, separate from the town of Oak Ridge, housed up to 12,000 workers in the gaseous diffusion plant area.

Meals on the grounds

Six cafeterias were operated to serve breakfast and dinner. No lunches were served to construction workers and canteens were not permitted in the working area. However, at noontime trucks equipped as stores were driven into the work area to sell sandwiches, cakes, soup, coffee and cold drinks.

No organization is any better than the key personnel. The J. A. Jones Construction Co. had a versatile, experienced, and loyal organization on this tremendous undertaking. and each of those in key positions were top men in their specialty. The whole organization was imbued with the idea that they were building something vital to the war effort.

The management is convinced that it successfully met the demands for speed and perfection, and completed the atomic bomb plant on schedule. because of the type of organization used—flexible, departmentalized, yet closely integrated, and because of the calibre and loyalty of its supervisory forces, as well as of the rank and file of its employees and subcontractors.

Building A Power Plant in 10 Months

John D. Watson
Chief Engineer, J. A. Jones Construction Co., Inc.

GROUND WAS BROKEN for the boiler house and turbine room foundation on June 2. 1943, and the first unit of a 238.000-kw. steam power plant, needed at the Clinton Engineer Works in Tennessee went on the line April 15. 1944. Built in 10 months the plant has three boilers. each with a rated capacity of 750,000 lb. per hr. of superheated steam at 1,325 psi. and 935 deg. F. and includes several turbo-generators, ranging in size from 1.500 to 35.000 kw. It is believed to be the largest initial steam installation ever made and was built to meet a large demand for firm power that was necessary for the gaseous diffusion method of separation of Uranium 235 from U 238.

Although wartime shortages made construction difficult they also contributed to the fast start that it was possible to make on the job. Two of the boilers and several of the turbines and generators, for example, were being manufactured to replace obsolete vertical units at the Fiske St. station of Commonwealth Edison in Chicago, and because of wartime necessity were commandeered for installation at C.E.W. In addition much other equipment was obtained on high war-induced priority.

Specialist firms used

Urgency of the operations compelled the architect-engineers to let, simultaneously with the general construction contract, separate prime contracts for the furnishing and fabricating of the boiler house and turbine room structural steel, for the electrical work, for the piping, for the furnishing and erection of the boilers and the pulverizer mills, as well as for the furnishing and erecting of the precipitators.

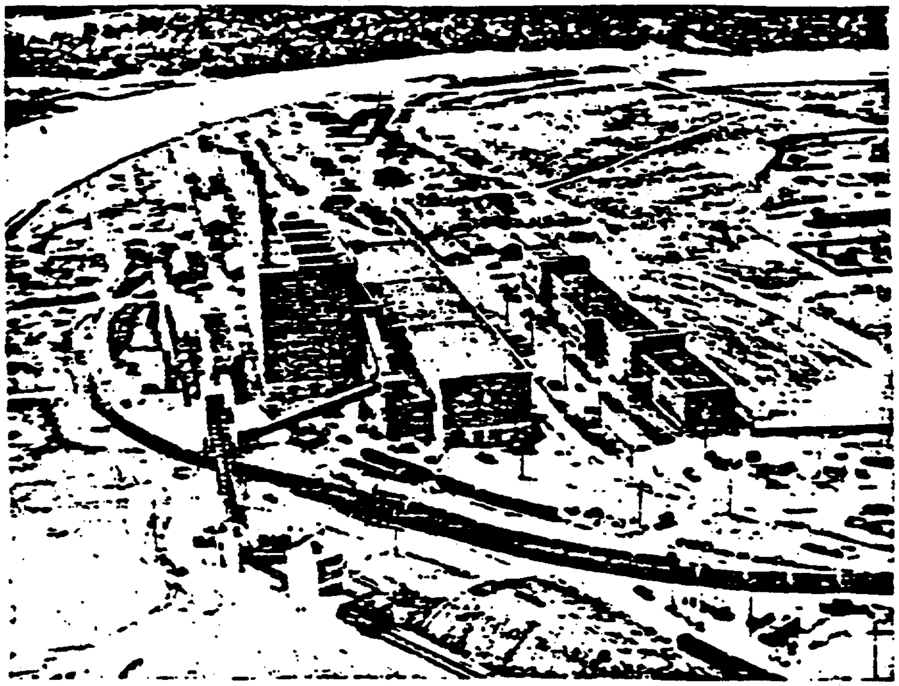
The general contractor, in turn, let to subcontractors the caisson foundations for the boiler house. erection of the main structural steel frame for the boiler house and the turbine room, guniting in the coal bunkers and slag tanks, turbo-generator erection. and insulation.

In addition to the boiler house and turbine room there was constructed for power control a main switch house of reinforced concrete and brick (69 x 635 ft. in plan), an auxiliary switch house for the operation of boiler auxiliaries. a river intake crib and tunnel for condenser cooling water, a pump house, a discharge tunnel and flume, a 154 kv. outdoor switch yard. a service building and complete coal unloading, breaking. conveying, stacking and recovery facilities.

The structures required a total of 87,000 cu. yd. of concrete, 4.600 tons of structural steel. and 4.300.000 brick. The peak employment was 5,600 men, most of whom worked on a 10-hr. day shift.

Difficult access

The site selected for the power plant was at an isolated area on the Clinch River, seven miles from a railroad



Steam power plant of 238,000 kw. capacity built in record time at Clinton Engineer Works. Note 225,000 ton coal storage and recovery equipment in foreground as well as large available work and storage area around the entire plant. Building at right is main switch house. The Clinch River, source of cooling water, is in the background.

and accessible only over narrow gravel roads. One access road was restricted by a hand-propelled ferry with a capacity of two passenger automobiles. The other road had a single lane, 8-ton capacity bridge. No electricity or telephones were available immediately, and other contractors, already in the area, had absorbed all available labor.

Yet, six weeks after the first representative of the general contractor reached the site, a camp to house 1,500 men was opened, complete with mess hall, temporary water supply and sewerage system, and all major parts of the construction was underway. Construction of office, shop and warehouse buildings was carried on simultaneously with start of work on the power plant proper.

Building the power house

Several innovations in construction, as well as the letting of portions of the work to specialist firms, contributed to completion of the power house on the exceedingly rapid schedule carried out.

Plans for the structure for housing the boilers and turbines were available from Chicago and were adaptable to the C.F.W. site, with modifications to add space for an additional unit. The original steel already had been erected and enclosed at the Chicago plant so it was not moved. However, the same fabricator was directed to duplicate steel, so that new shop drawings were not required and steel could be immediately fabricated and delivered for the structure, which has a height equivalent to a 14-story building.

Doubtful foundations

The site for the plant, to be near water necessary for condenser cooling and low to avoid pumping, is on the flood plain of the Clinch River. Underlying soil is clay, giving way to shale and shattered lime-stone interspersed with clay seams and a 1- to 5-ft. thick layer of sand over rock at a depth of 35 to 40 ft. The original plan for support of the boilers was to sink forty 6-ft. dia. caissons by the Chicago-well method, *i.e.*, excavation would be done in the open in steps of 5 ft. and, after the excavation was completed in each step, vertical wood lagging would be placed and supported by steel rings.

In putting down the caissons, it was possible that one or more of them would strike a seam in the rock that was open all the way to the river, a distance of less than 500 ft., or the sand stratum directly over the rock might have been under full hydrostatic pressure from the river. If either of these contingencies occurred the use of compressed air would be required to reach a satisfactory foundation, and the change from open excavation to compressed air would be difficult and time-consuming.

Dropped-in caissons

To eliminate the delays that might follow a blow-in, the contractor recommended "dropped-in" concrete caissons, and their use was accepted by the engineers. In this method, precast concrete caissons were sunk to solid rock by open dredging. The top of the caisson was poured with a circle of anchor bolts so that an air-lock could be installed in a few minutes. A battery of compressors was made available and air-locks were brought to the job. Fortunately the use of compressed air was not required though some difficulty was encountered that required considerable pumping.

Security restrictions imposed on everything connected with the atomic processes limit what can be told about the plant. However, a large number of construction expedients were used that assisted materially in cutting down the time required for construction. For instance, to avoid slow and expensive work in the Clinch River, bulldozers were used to push earth into the edge of the stream on which a 62 x 57-ft. cofferdam was built for construction of the intake crib. On this "island" a double timber frame was set up and steel sheetpiles were set around it and driven to rock. Earth inside was clammed out and used to help seal the bottom of the sheets where, due to the irregular rock bottom, the cofferdam could not otherwise be made watertight.

Ten acres of built-up ground

Excavation for the discharge tunnel was carried down to groundwater with tractors and scrapers. When the bottom became soft, work was continued with draglines and clamshells. The spoil from all excavation was used to fill low ground, ten acres thus built up being used for a material storage yard.

Foundations were ready and steel available before a railroad spur into the job was completed so structural members for the boiler house frame had to be trucked-in 13 miles from the nearest siding. First of the three

40-ton drums for the first boiler was placed about four months after start of the job, while erection of 4,600 tons of boiler house and turbine room structural steel was completed in 85 elapsed days.

Two guy derricks were used to erect the heavy structural steel frame of the boiler house. Tugger hoists secured to the columns handled the lighter pieces. Crawler cranes began setting steel in the pump bay and in the turbine room before the boiler house was topped out.

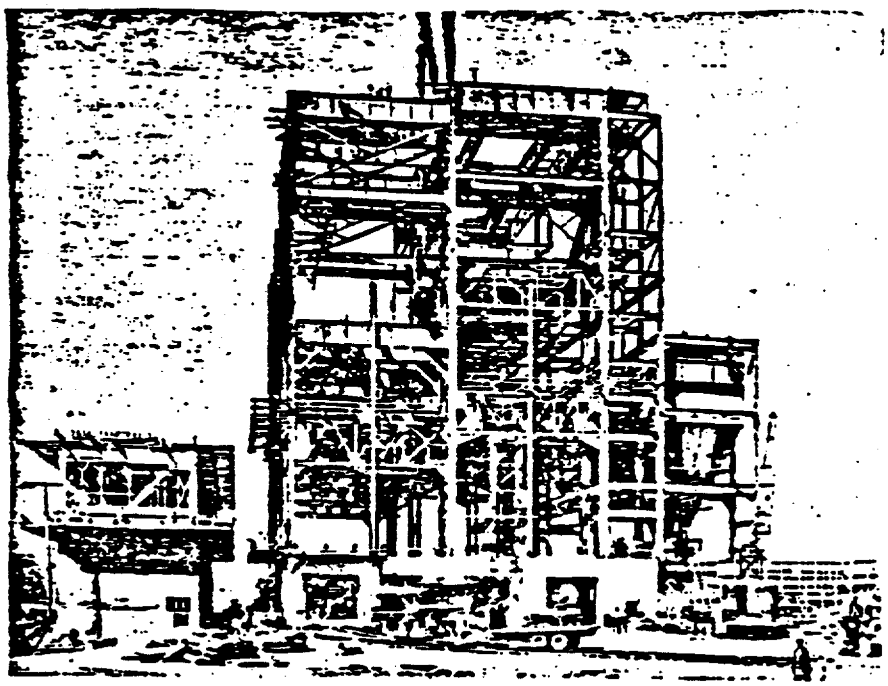
Gallery steel set early

Somewhat of an innovation in power house construction was the early installation of framing and grating for the galleries. Ordinary practice has been to use temporary scaffolding and ladders to avoid interference with placing the piping and auxiliary equipment. Actually, installation of the permanent gallery steel gave access for all crafts with a minimum of confusion, and substantially speeded the work.

To save four weeks time in enclosing the boiler house the brickwork was started from scaffolds hung from about mid-height of the structure, while erection of steel to the top was continued. Openings were left in the walls and in the roof to permit bringing in heavy equipment. Use of precast slabs for the roof made it a simple matter to leave openings wherever desired.

Other factors contributed substantially to the speed of construction. One was the availability of adequate space around the structures for access to all sides and for storage of parts and supplies in such a way that any needed piece could be moved in easily. Railroad tracks were laid into each end of both the boiler house and the turbine room so rail cars could be used for final delivery of heavy material, even before the rail connection to the outside was completed. Work was organized on a production-line basis with the same crews doing the same work for each of the several units.

Another important factor in speed was availability of all kinds of large equipment. Due to the size and complexity of other work underway nearby almost every known kind of construction equipment was in use on the site and could be made available as needed for the power house construction. For instance, the overhead cranes were too slow for placing mass sections of concrete, so concrete, delivered by mixer-truck, was pumped from a machine set up outside the building.



Concrete-frame switch house for boiler auxiliaries rises at left as guy derricks erect steel for the boiler house. The boilers are suspended on springs from the framing seen at the top center of the steel, while stacks and fans occupy the bay to the left. Note bricklayers' scaffold hung from mid-height.

Schedule difficult to meet

By Dec. 1, six months after start of construction, the building was enclosed. Window frames were late, but anchorages were arranged to hold them without "toothing" the brickwork. Temporarily, all openings were covered with tarpaulins, and a steam heating system was improvised to replace salamanders, making working conditions reasonably pleasant.

After Christmas, the pressure to meet the scheduled completion date became intense. The boiler erector began double shift operations, the night crew sorting out and placing the material so the day shift could devote full time to erection. A satisfactory hydrostatic test on boiler No. 1 was 23 days ahead of schedule.

Installation of the pulverizer mills and the forced and induced draft fans of the first unit was completed in February, but receipt of the slag tanks was delayed. Date of delivery of the boiler feed water pumps was critical and uncertain, and receipt of piping and valves for the first turbine had slowed down to a trickle. And finally, the last shipment of parts for the first generator was mistakenly shipped L.C.L. instead of by express.

In March, the situation looked better. The intake crib and tunnel, pumphouse, and discharge tunnel were given a final inspection and accepted. The drying-out fire was started in boiler No. 1 on March 8,—one week ahead of schedule.

In April, boiler No. 1 was tested under steam pressure and the safety valve was set. The first turbo-generator was turned over slowly under test, and finally on the morning of April 15, the machine was brought up to speed, synchronized, and put on line. By the end of April, building construction, except for painting, was complete in the turbine room, the service building, the auxiliary switch house, and the main switch house; and the boiler house was 95 percent finished. The second and third boilers were completed three and six months, respectively, after the completion of the first.

Lt. Col. William P. Cornelius represented the Manhattan District of the Corps of Engineers. A. A. Nickman, resident engineer for Commonwealth Edison on the Fiske St. station work, who already had planned the installation in Chicago, was retained by Kellex Corp. to represent the architect-engineers on the project. For the general contractors, J. E. Davidson was project manager, W. H. McWhirter, general superintendent, and the writer, chief engineer.

Electrical work was performed by A. S. Schulman Electric Co. of Chicago, and piping by William A. Pope Co., also of Chicago. The Foundation Co. of New York supervised installation of the "dropped-in" caissons, and Bethlehem Steel Co. erected the structural frame for the main plant.

Boilers were furnished and erected by Combustion Engineering Co., and precipitators were supplied by the Research Corp. The turbo-generators and condensers were manufactured by Allis-Chalmers, General Electric and Westinghouse.

Compacted Fill Equals Natural Ground

John D. Watson
Chief Engineer

O. R. Bradley
Soils Engineer

J. A. Jones Construction Co., Inc.

MOUNTAINOUS NATURE of the terrain at the Clinton Engineer Works, which made the site desirable from many viewpoints, made it difficult to obtain unyielding foundations. This was especially true of support for the huge U-shaped building (2,500 x 400 ft. for each leg and 400 ft. across the inside of the U) that houses the main plant of the gaseous diffusion process for separation of U-235.

The design requirements provided that the same floor elevation be maintained throughout each of the many separate but connected building units composing the U thus, requiring construction over high fill and adjacent deep cut areas. Each building consists of a basement and first floor of reinforced concrete, while the framing of the second and third stories is structural steel. The ground elevation inside the U is the same as the elevation of the first floor slab, while the area around the outside of the building is graded to the elevation of the basement.

A site of 130 acres was prepared in accordance with this requirement for a single building area. During a four-month period the site was graded and concrete operations advanced enough to stay ahead of structural steel erection. Topography of the site was such that fills up to 23 ft. in height were required, while a cut 46 ft. had to be made on one hill. In all, more than 2,000,000 cu. yd. of earth were moved.

Three plans for support

The question of how to put in the building foundations on the fill areas of the site was the subject of much discussion. One plan was to place spread concrete footings on undisturbed soil, and extend columns up to the basement floor level. Fill was subsequently to be placed between the footings and columns by dump trucks. This method was elimina[ted] because no grading subcontrac[tor] could be found who would undert[ake] the filling between the footings a[nd] columns in the time allotted.

Another plan was to complete grading operations as rapidly as p[os]sible, and drive pile supports sep[ar]ately for each footing. This wo[uld] have been a slow and costly operati[on] and would have failed to provi[de] adequate foundations for many pie[ces] of heavy equipment that were to [be] set in the basement and whose lo[ca]tion had not then been established.

Finally, the suggestion was ma[de] that all filling be done in 6-in. laye[rs] which would be thoroughly co[m]pacted with sheepsfoot rollers aft[er] the manner of earth dam and hig[h]way embankment construction. The[n] the footings could be founded direct[ly] on top of the new fills, a revolutiona[ry] idea in the field of building constru[c]tion. This method was adopted.

Excess moisture caused difficulty

A major difficulty encountered i[n] making the fills was the fact that th[e] natural moisture content of the re[sidual] clay was considerably above the opt[i]mum required for compaction; fo[r] example, 5 ft. below the natur[al] ground surface the moisture conten[t] averaged 33 percent. As a result a[ll] the soil used in compacted fills ha[d] to be plowed, aerated, and dried out.

After careful stripping of all vege[tation] and top soil down to firm sub[]soil some 300,000 cu. yd. of com[]pacted fill was placed in the area[s] shown dotted in Fig. 2. In additio[n] to the specially compacted fill, 875,000 cu. yd. of material was placed in the center of the "U" and on the out-

Fig. 1. Typical of support problem is area where ground changes from cut to fill and where equipment requiring unyielding support is in a varied pattern. Winter concreting is underway in background.

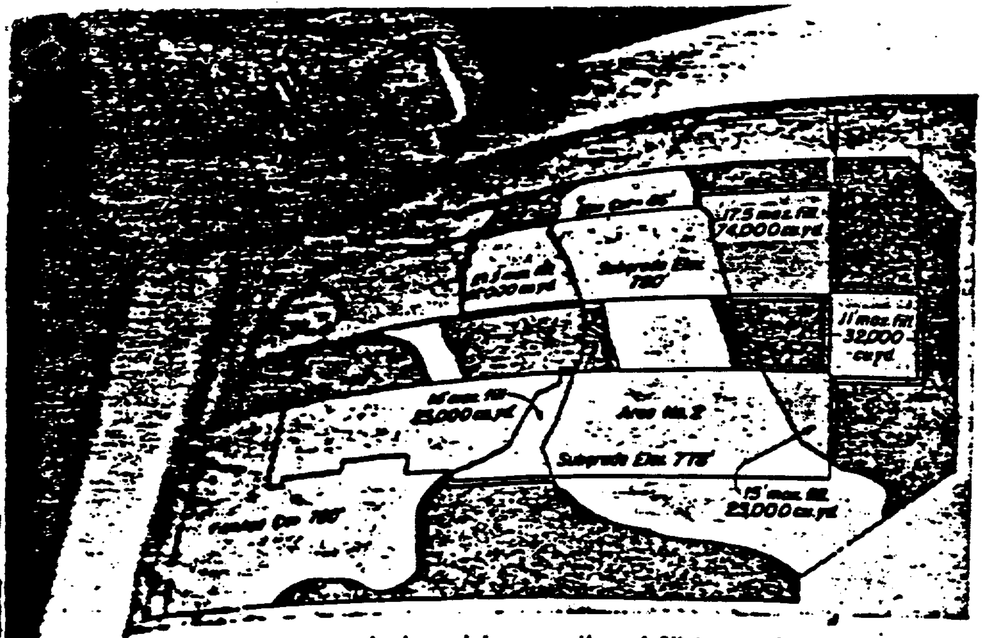


Fig. 2. Dotted areas required special compaction of fill to provide support equal to that of natural ground. Dark shaded areas are fill where reasonably good material was spread in 6-in. layers and compacted only by equipment travel.

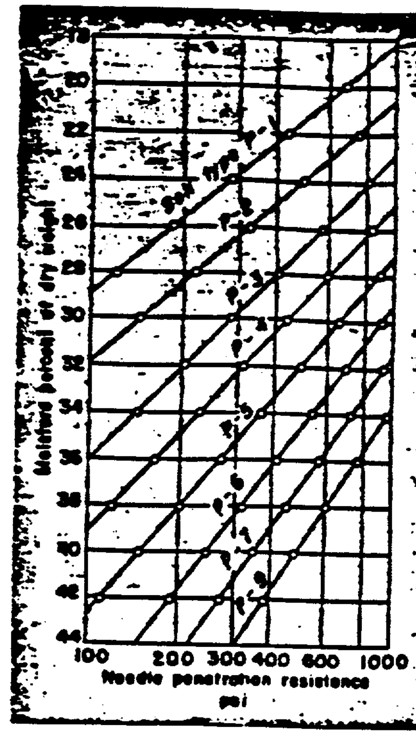


Fig. 4. Moisture-density and needle penetration resistance curves for compaction control of different soils.

side of the buildings. Only material with reasonably good bearing qualities was used for the outside areas and it was spread in 6-in. layers, but was compacted only by the travel of equipment. Excavation and fill was subcontracted to three firms, so filling operations were nearly always in progress on three embankments simultaneously, and sometimes on four.

Supplementary price for compaction

A fixed rate of 27c. per cu. yd. was paid for all excavation and dumped fill. The specially compacted fill under the building site was paid for by a supplemental, or additional, price of 39c. per cu. yd. in place, while a supplement of only 5c. was paid for fill material placed where special compaction was not required. This method of paying a premium price for compacted and special fill in place was decided upon when it was seen that much of the excavated material would have to be wasted either because it was too wet, or because it contained too much loose rock.

Original specifications for the specially compacted fill had provided that the material be placed in 6-in. layers at or near the optimum moisture content, and that the rolling be done with sheepsfoot rollers exerting a pressure of 300 psi. Rolling was to be continued until a density equal to 95 percent of maximum (as indicated by the modified American Association of State Highway Officials tests) was reached, and the completed fill was to have a dry density of 90 lb. per cu. ft. to carry a load of 5,000 lb. per sq. ft.

Actually, requirements had to be relaxed somewhat when it was found that three of the seven common soil types could not be compacted to a dry density of 90 lb. per cu. ft. with the equipment specified. The average dry density obtained in the embankments, however, was 87.5 lb. per cu. ft., which compared with 86.6 lb. per cu. ft. for undisturbed soil in the borrowpits.

Half of time lost

The placing of specially compacted fill under building sites began Oct. 10, and was completed Dec. 23, 1943. Between those dates there was a total of 1,390 possible working hours, assuming two 10-hr. shifts per day. Of this time 338 hr. was lost because of rain, 395 hr. because of excessive field moisture, 80 hr. because of frost

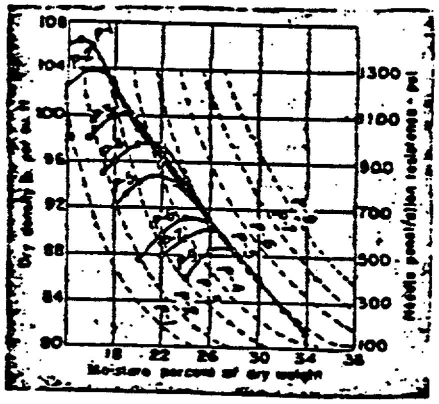


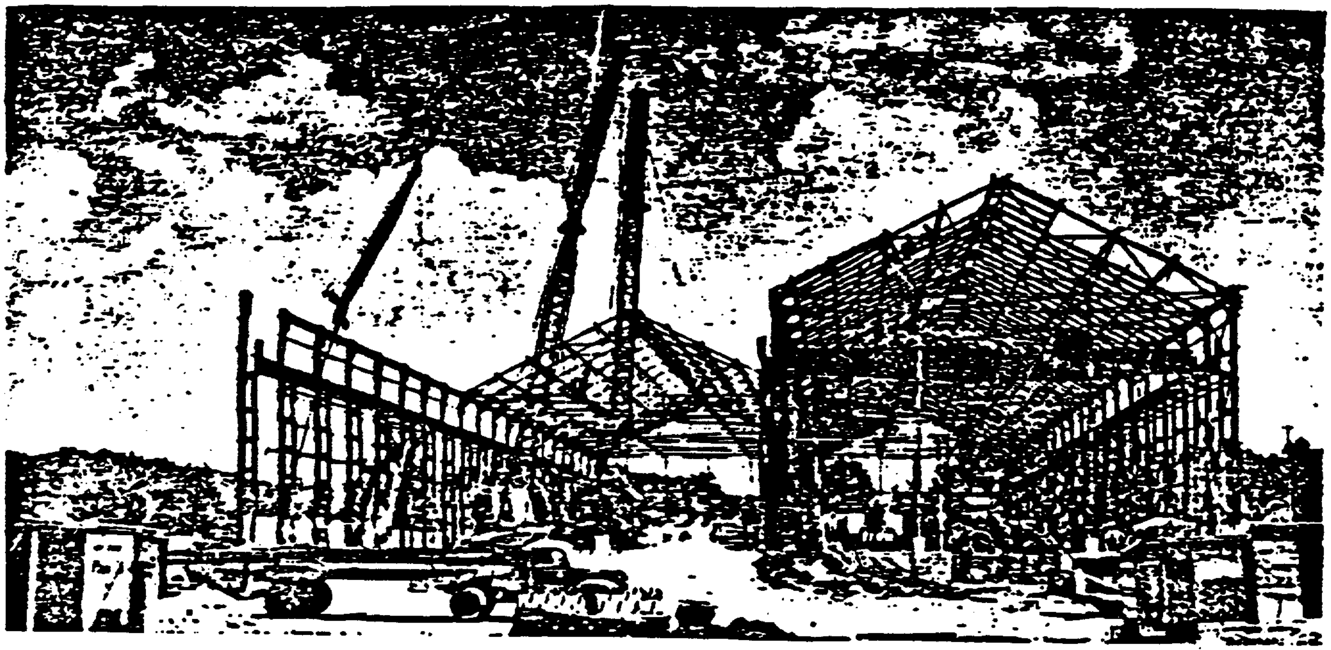
Fig. 3. Moisture content related to density and needle penetration for rapid identification of soil types.

in the ground. In each of the 577 hr. remaining the grading subcontractors had to average better than 500 cu. yd. of compacted fill.

Profit from TVA experience

Nine soil types were intermingled over the entire site with scarcely any excavation or borrow area composed wholly of one type. A satisfactory identification of the several types could not be made by eye, nor could testing be done sufficiently far in advance to take care of the sudden changes in types that were encountered. The Tennessee Valley Authority had had the same difficulty when constructing earth embankments for dams in this region and engineers on this project profited by TVA's experience, using methods of identification and testing similar to those devised by F. H. Kellogg, soils engineer of TVA. (*ENR*, Oct. 22, 1942, vol. p. 550)

The regular pattern of the penetration resistance—moisture curve is apparent in Fig. 3. If these curves are plotted on semi-logarithmic paper, Fig. 4, they appear as straight lines. By placing a sample of soil in a compaction cylinder according to standard methods, pushing a needle into the sample, and then by making a quick determination of the moisture content of the sample, two values



Warehouse built on sloping ground is supported on spread footings over compacted fill as much as 17 ft. deep. Fill for floor at car-door level is shown being completed by compaction rolls.

(penetration resistance and moisture content) are available to apply to Fig. 4 for a ready identification of the soil type.

The soil type in use having been identified, the density to be obtained was also known. Grading operations then could proceed with full knowledge of what amount of rolling was required to produce satisfactory compaction, provided of course that the field moisture content of the soil was sufficiently close to the optimum. Ellipitical needle points were used regularly in the field to determine when the rolling had produced a sufficient soil density. Successful use of penetration needles for this purpose was due to the fact that all the soil types encountered were clays that contained no gravel and practically no chert.

Results found excellent

At least once each day on every active fill area, and always when as much as 2,000 cu. yd. of fill had been placed, an undisturbed sample of soil was cut out of the embankment with a ring cutter, and the dry density of this sample determined in the laboratory. In this way daily checks were obtained on the accuracy of the needle penetration resistance.

Results achieved were entirely satisfactory, and two years after construction was completed no settlement had been discovered despite thousands of level readings made on the footings. When a large addition to the plant was begun early this year, the designing engineers required that all fill be placed under the specification for controlled compaction.

Lt. Col. William P. Cornelius represented the Manhattan District for the Corps of Engineers on this project. The Kellex Corp. of New York was the architect-engineer. The J. A. Jones Construction Co., Inc., of Charlotte, N. C., was the general contractor, H. V. Appen being project manager, A. C. Samford, general superintendent and John D. Watson, chief engineer. O. R. Bradley, as soils engineer, directed all field testing and placing of fill. The grading subcontractors were Oman-Creighton, Nashville, Tenn., Wolfe-Michael Construction Co., St. Augustine, Fla., and the D. W. Winkelman Co., Syracuse, N. Y.

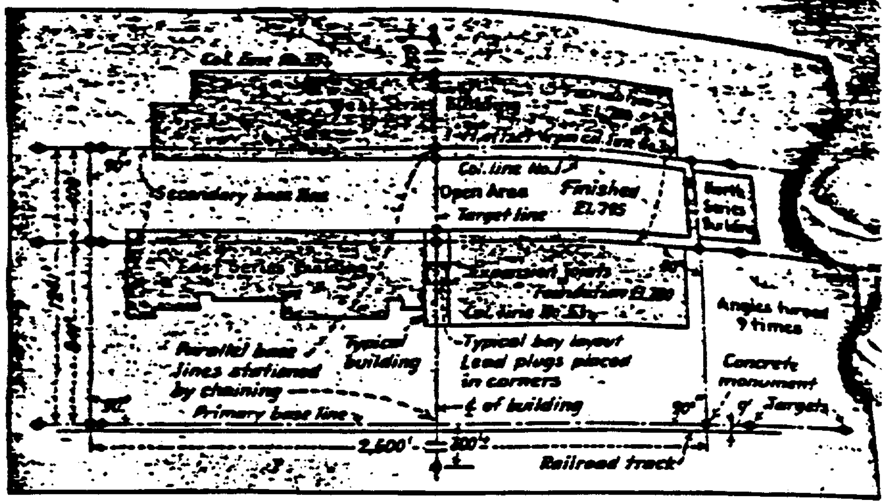
Surveying for Fast Construction

Howard R. Kornberg
Construction Engineer, J. A. Jones Construction Co. Inc.

THE SIZE of the main building and the speed of the work made the field engineering layout for the gaseous diffusion plant at Clinton Engineer Works a major problem in itself. Though the main building appears to be a single "U"-shaped structure, actually it is composed of a large number of separate building units. A single roof covers the whole group, but between every adjoining unit there is a multitude of piping interconnections. This type of construction necessitated a unique, and somewhat complicated, layout in order that the separate units could ultimately be tied together to form a single unified process plant.

To accomplish this result a primary base line was established away from the building site, where there was no possibility of disturbance, and secondary base lines were run inside the building site, and parallel to the primary base line. The primary base line was run 9 ft. off the center line of the construction railroad main line, and was 2,600 ft. long. A concrete monument was set at each end, and intermediate concrete monuments were placed at about 500-ft. intervals. The secondary base lines, run inside the building site, were offset 1 ft. from the center of column line No. 3.

Two targets were set up on each end of each base line. One target was set completely off the building site where there was no danger of its being disturbed. A second target was placed on the building site, to be used in case visibility became poor on account of darkness or fog. Every target had its description clearly painted in large letters on a board directly under the target. In this way the instrument man always was able to identify the target through the telescope, and the possibility of error due to reading the wrong target was largely eliminated. The targets used were 4 ft. square and were painted red and white in alternate triangles. Such a target is quite satisfactory for a 2,000-ft. foresight.

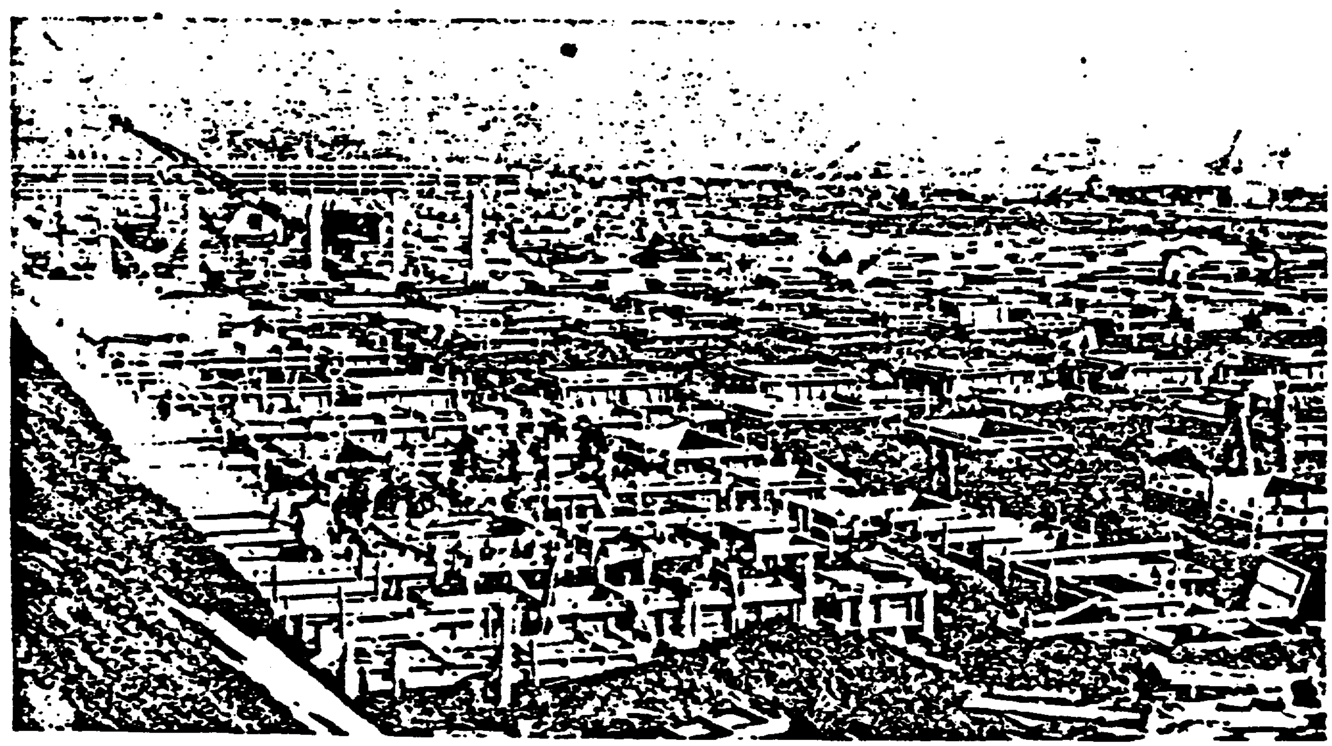


Base line and target layout for accurately locating points over a 60-acre building.

In establishing the secondary base lines the 90-deg. angles were turned at least nine times and averaged to insure the accuracy of the rectangle. Once these rectangles had been established and checked, it was possible to layout any building for any desired order of construction. Actually, the sequence of construction was very irregular, and this type of layout was very necessary. The primary and secondary base lines were laid out while grading operations were in progress, and it was impossible to establish all corners permanently until the grading was complete.

Each building unit is composed of a basement and first floor of monolithic reinforced concrete. The second and third stories are framed with structural steel. The footings were poured directly on top of undisturbed soil in the cut sections, and on top of compacted fill in the embankment sections. The ground elevation inside the "U" was the same as the top of the first floor slab, and this high level of ground was maintained by a reinforced concrete retaining wall located between column line Nos. 2 and 3, very close to the secondary base lines which were on the basement floor level.

The center line for one building unit (see layout sketch) was run from the primary base line to a concrete monument located at the lower, or basement floor, level along the outside wall (Col. Line No. 53 for the east series of buildings). This monument was the established point from which all east series footings were located. Then the building center line was extended to a concrete monument on the secondary base line. Subsequently, center lines for all other buildings on the east series were established by precise chaining, north or south along the secondary base line.



A two-man instrument party was required for each 500 construction workers on the gaseous diffusion plant at Clinton Engineer Works. Shown here are footing and column forms for the main building.

Another concrete monument was set on the building center line at the No. 1 column line on the upper, or first floor, level inside the "U" on the east. From this point an intermediate set-up was made to establish a concrete monument on the building center line at column line No. 1 for the western side of the "U". Targets were then established on the east and west, outside the building site on the center line for the single building unit.

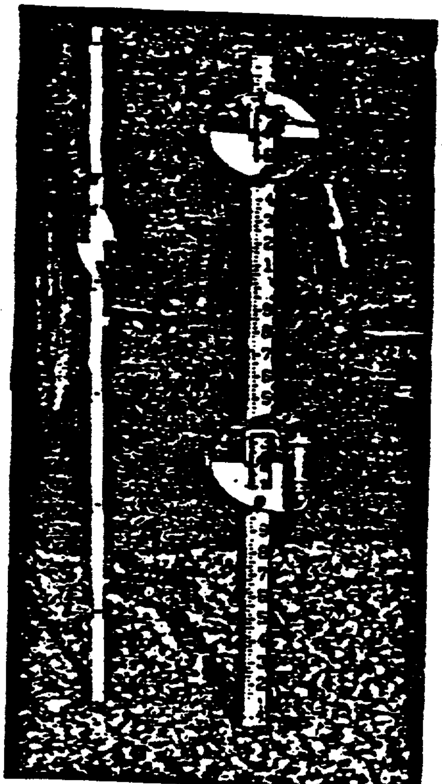
Machinery layouts

Each building unit (width between 50 and 200 ft.) was separated from the adjoining units by expansion joints, and transverse expansion joints were located about 75 ft. apart. Most of the building units are nearly 400 ft. long, and consequently there was considerable movement in the structure due to temperature changes. No attempt was made to make machinery or piping layouts until after a building was under roof, as this tended to reduce the temperature fluctuations and decreased the amount of movement.

After the structural steel for a building was erected and plumbed, the building center line was projected on all floors. Lead plugs were placed in the concrete slab of the first floor and punch marks were made in the steel. This true center line, established separately for each building unit, provided for any variations occurring in the location of one building with respect to another, and it also gave all crafts and subcontractors a common starting point. With all piping and equipment tied together from floor-to-floor, as well as from building-to-building, this common control was very essential. Tolerances in grade were limited to 0.005 ft., and line variations to 1/16 in. plus or minus.

Accurate rectangle established

After a building was under roof, a layout rectangle was established on the first floor slab for each bay. Lead plugs were set in the concrete for the corners and from these centers all equipment was located. Each line was marked, and the layout pattern was typical, so that any man could go into any building and know where to begin. In locations where points on the floor would be covered by equipment, pads were welded to the under side of the structural steel beams so that plumb bobs could be hung from the ceiling.



ENR staff photo

Target with flashlight battery and bulb to throw light on vernier is displayed on a cut-off level rod. At left a 6-ft. rule and plumb bob target have been converted to a level rod, with vernier added for reasonably accurate readings. Both devices were developed on the job by S. S. Chappell.

Lighted level rod

A new level, in perfect adjustment, was reserved for the establishment of all bench marks. Bench mark leveling was done only after work hours in order to avoid vibrations caused by construction equipment. For ease in handling inside the buildings standard level rods were cut off to convenient lengths. On these rods a one cell battery and flashlight bulb was mounted on the rod target to permit accurate readings in poorly lighted corners. Some levels were equipped with similar lights to facilitate adjustments of the bubble tube.

In the basement and on the first floor two types of benchmarks were established. A painted scribe mark was made on every other column about 1 ft. above the floor. In strategic, but out of the way, locations a 1/4-in. bolt was put in the wet concrete of the floor slab, and left protruding about 1 in. for all elevations requiring any refinement, since the scribe marks on the columns were scarcely good to more than 0.01 ft. Above the first floor all elevations, not requiring an accuracy greater than 1/8 in., were taken directly from the structural steel framework.

Personnel requirements fluctuated in accordance with the types of work underway but at no time was it possible to employ experienced rodmen since the young men who usually do this work were all in the army.

As far as possible, instrument parties were given repetitive assignments so that they became proficient on one operation and followed it through the entire job. For example, two parties started on the layout of footings. By the time footings for 20 buildings had been placed, the men had become so proficient in the task that one party could do all the work.

For layout inside the buildings it was found that a two-man party could work very successfully. These two-man parties carried both a transit and a level so that they could switch momentarily from line to grade. With this system one experienced field engineer was required at the peak of the construction period for every 250 construction workers, to establish and maintain the layout for all buildings, roads, utilities and subcontract work.

One man was held responsible for the accuracy and condition of all instruments, checking them systematically for adjustment and cleaning them periodically. Tapes and level rods were replaced frequently to avoid errors caused by misreading defaced numerals.

Usable ideas developed

During the progress of the work the men were alert to invent and develop ways and means to improve or simplify the particular job they were doing. It was learned that worn-out triangular saw files, contributed by the carpenters and ground flat on one end, make an ideal tool for putting scribe marks on concrete. Shoe polish paste is an excellent paint substitute for stencilling numbers on concrete columns. For marking on floors that will be covered with dirt red paint is more easily seen than white. A converted plumb bob target mounted on a 6-ft. rule made a convenient rod for checking elevations in cramped places.

Building a City from Scratch

Ernest A. Wende
Engineer, U. S. Engineer Office, Oak Ridge, Tenn.

Prime considerations in planning and building the housing development necessary to construction and operation of the Clinton Engineer Works were speed, saving of critical materials and minimum interference with the local labor supply. These requirements were met by adapting surplus materials and housing from other war projects, by laying out the town on contour-planning principles, and by eliminating much on-site labor through simplification of design and by prefabrication at localities well removed from the construction site. All of these expedients proved highly effective.

DURING THE SHORT SPAN of two and one-half years, the full fledged city of Oak Ridge mushroomed from the sparsely populated farm land of Eastern Tennessee. Highly publicized as the "Home of the Atomic Bomb," this community was constructed as an incidental by-product of the largest and one of the most effective projects for war. With its population of nearly 75,000, making it the fifth largest city in Tennessee, the new community has nearly 10,000 family dwelling units, 13,000 dormitory spaces, 5,000 trailers and more than 16,000 hutment and barracks accommodations, together with all of the supplementary facilities that make up a complete and integrated municipality.

Oak Ridge is the residential center for the Clinton Engineer Works. It is also the administrative center for the entire Manhattan District, which includes the Hanford Engineer Works near Pasco, Wash., and numerous other installations. The site, a hilly and wooded section $1\frac{1}{2}$ mi. wide and $6\frac{3}{4}$ mi. long in the northeast corner of the 59,000-acre government reservation, was selected to provide a reasonable separation from the plant areas of the Clinton Engineer Works and to create a desirable housing development.

Much of the town was laid out with rear entrances toward the street and with porches and main entrances facing spacious grassed and wooded areas. Over the greater part of the town the raw scars of construction have now been covered by resident-created lawns and gardens, with the result that the community has a permanent and pleasing aspect.

As Architect-Engineer-Manager for all of the early construction at Clinton Engineer Works, Stone & Webster Engineering Corp. was assigned the job of providing living quarters for personnel necessary to plant operation. This phase of the development was turned over to the architectural firm of Skidmore, Owings and Merrill, of Chicago and New York which prepared building plans and town layout based on housing designs developed by the John B. Pierce Foundation. The A-E-M firm, however, was responsible for coordination of the work, procurement of materials, con-

Winding roads and contour location characterize Oak Ridge, Tenn., built in $2\frac{1}{2}$ years to house 75,000 people.

Attractive living quarters, such as this 3-bedroom house, help to hold hard-to-get top personnel.

tract supervision and construction of roads and utilities.

After this relatively normal beginning the town passed through three principal phases of expansion, telescoping the normal growth of a century into only 2½ years. As a result the city's present area is nearly double that included in the first plans.

Roads and utilities

The main roads of Oak Ridge follow contours on the ridge, with frequent connections to the valley by thoroughfares following winding routes along natural grades. "Avenues," usually named for states, connect the valley with the ridge, "drives" parallel the ridge; "roads" are short secondary loops stemming from avenues; "circles" as the name implies, come back out on the same route; while "lanes" are dead-end. All secondary streets have names starting with the same letter as the avenue to which they connect and are in alphabetical order starting from the valley. Thus, it is relatively easy to find one's way through a strange area on the winding roads.

Little cut and fill for streets

Streets are all 30 to 40 ft. wide, including shoulders, and generally follow the surface of the ground, average cut and fill being 1.3 ft. This required grades up to 12 percent (few sections are more than 8 percent), but it reduced substantially the time required for construction.

The avenues are paved with a bituminous surface treatment, but secondary streets, with few exceptions, are surfaced only with crushed stone. Drainage is by side ditches, with only a few hundred yards of curb and gutter along the 100 mi. of road in Oak Ridge.

Water lines, which follow the streets, are laid about 3 ft. deep and 1 ft. inside one edge of the road metal, where they can be reached without closing the road. Sewers generally are laid behind the houses and follow minor valleys to the trunks. There are some crushed stone sidewalks in Oak Ridge, but the only concrete ones are some short lengths in two of the main shopping centers.

A minimum of utility installation was made throughout the area. While electricity is used for cooking, none of the services is metered and telephone lines, limited to essential personnel only, are carried on the same poles as electric lines.

The architects were retained in February, 1943; in March, work started on the first 1,000 houses; and by August the first phase of the building program was all under contract in what later came to be known as "East Town". This included the construction of 3,050 family dwelling units ranging from 1-bedroom apartments to 3-bedroom houses, three "efficiency" apartments buildings, seventeen 150-man dormitories, a commercial area, a 50-bed hospital, four schools and other essential community facilities. The last units of the first group were completed during May, 1944, roads, utilities and miscellaneous buildings having kept pace with the rapid growth of the town.

In general, living facilities provided at Clinton Engineer Works are the minimum consistent with getting people to come to the project and stay there. In like manner, administrative and commercial buildings are of "five-year" construction with no frills.

In designing the first group of houses a prime consideration was the minimum use of critical materials such as lumber, copper and steel as well as minimum demands for labor on the site. An unusual feature of the design, to achieve the minimum of on-site labor, was the use of prefabricated panels consisting of a thick layer of fiber board with ⅛ in. of asbestos-cement bonded to both sides. Panels are fitted into slotted 4x4-in. posts and provide a complete interior and exterior wall in a single section.

Contracts by 1,000-house units

Contracts were let in units of 1,000 houses to permit assembly line construction technique. Lumber was precut and light roof trusses assembled at central mills on the area to minimize the use of hand tools. The wall construction described resulted in use of casement windows and screens sized to conform with standard panel widths, thereby involving a minimum of cutting and fitting. The roof consisted of lapped sections of insulation board encased in 90-lb. mineral-surfaced roofing. Thus, sheathing, roofing and insulation were provided in a single rapidly-laid unit.

For the four schools built under the initial program similar construction combined with brick resulted in modern and attractive structures. "H" type dormitories and other miscellaneous structures were designed by Stone & Webster Engineering Corp.

and are of conventional frame construction.

The second phase of the town construction program, largely built at a new "West Village," was primarily a low-cost housing development consisting of 4,800 family quarters. 52 dormitories, schools, cafeterias and supplemental buildings. The Tennessee Valley Authority, to provide temporary housing for construction workers, had developed a 1-, 2- or 3-bedroom "trailer house." This house could be purchased assembled in 2. 3 or 4 sections and moved on trucks to the job for final assembly with a minimum of on-site labor. TVA cooperated in making plans available, and the type was adopted with very little modification for 2,600 of the units.

Site assembly in 8 hr.

One of these dwelling units could be assembled ready for occupancy in about 8 hr. Post foundations proved to be inexpensive and rapidly constructed. Use of plywood for interior and exterior walls provided sufficient additional strength so that light 2-in. framing could be used throughout the structure. Other important features of these units included careful space utilization and the use of some built-in furniture.

Another 1,000 dwelling units were transferred from other war plants where they had been provided by the Federal Housing Authority but were no longer needed. These stove-heated buildings, of frame construction on post foundations, contained either two- or four-family units. Of panel construction, this type of structure is considerably more expensive to assemble than the TVA type, but is less costly to transport because more compact packing is possible.

On the second phase of the town construction program Skidmore, Owings and Merrill laid out the addition and designed the houses and utility systems, while Stone & Webster let and supervised the construction contracts. On a third phase of construction, made necessary as plants continued to expand, the architectural firm worked as prime contractor on design and supervision of construction contracts, which were let directly by the Manhattan District.

For the latter work, early in 1945, 20 dormitories and another 1,000 TVA-type houses were authorized as well as 1,000 marginal-type units designed to provide the absolute minimum in family accommodations. The latter consisted of a 1-story, 2-family dwelling 20x28 ft. in size constructed of light plywood panels and supported by 4-in. posts. Windows, without hardware or counter weights, drop into wall recesses.

This last construction program was about half completed when news of the Japanese surrender resulted in a partial cutback.

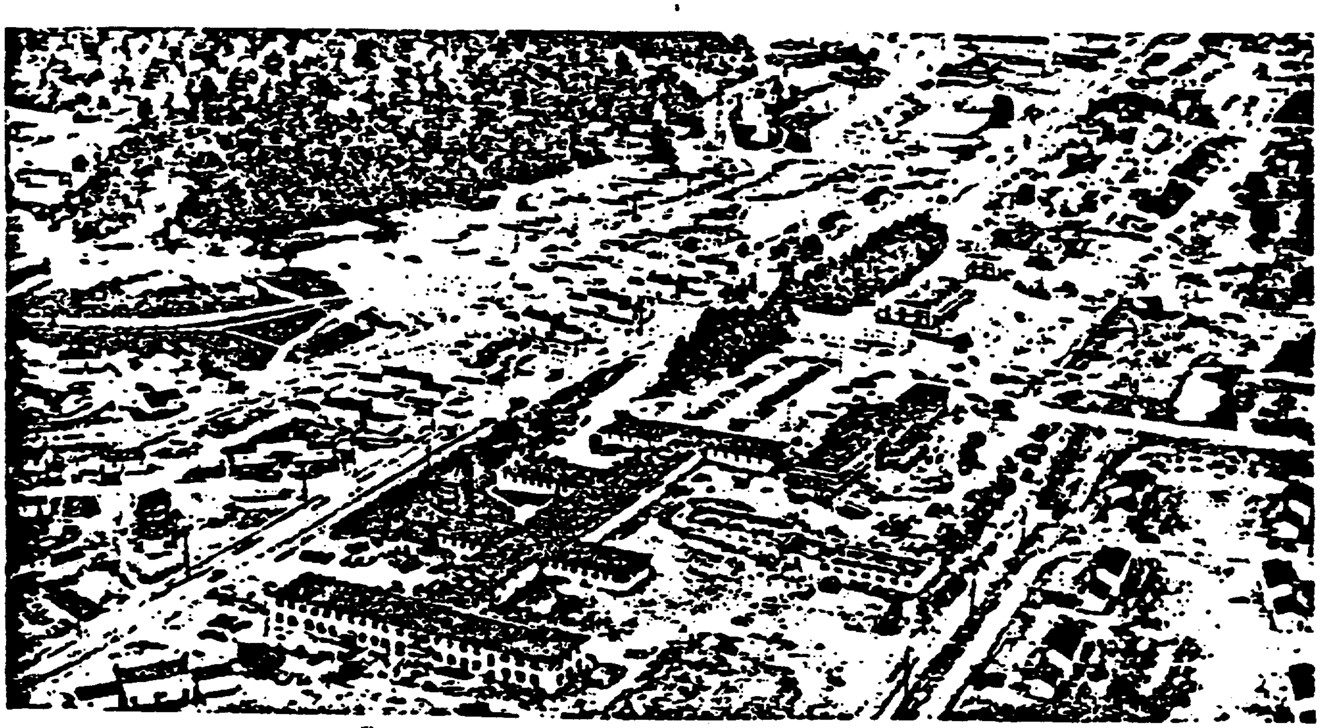
City managed on fixed-fee basis

Oak Ridge is operated as a military reservation governed by the commanding officer, in this case Col. Nichols, the district engineer. There is no mayor, but a voice in the administration on the part of the people is afforded by an advisory committee. For operation, the functions of a public utilities department have been carried on by an organization formed by Turner Construction Co. and known as Roane-Anderson, named after the two counties in which Clinton Engineer Works is situated.

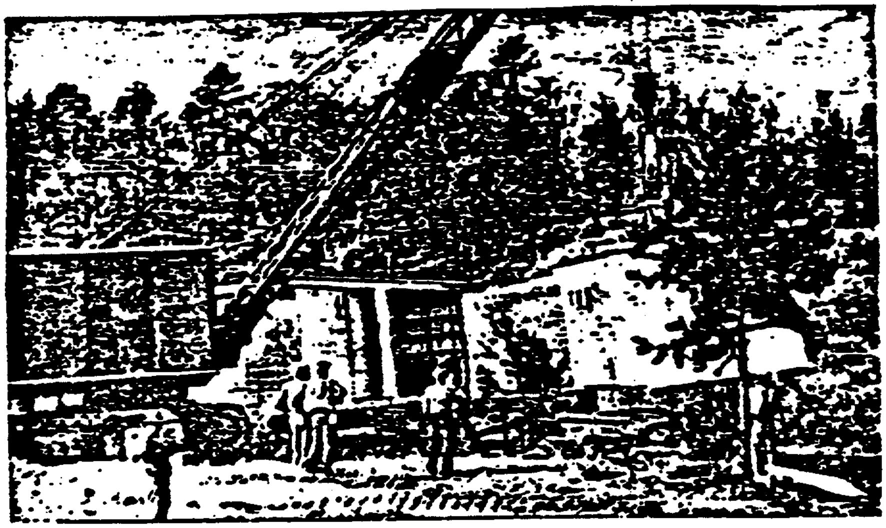
Until recently Roane-Anderson operated the entire town with its own forces. Included in its scope were rental and upkeep of houses and dormitories, operation of the cafeterias, buses, fire and police service, garbage collection and the like. The service was handled like other fixed-fee contracts on the project.

Now, many of the services, such as operation of the dormitories, houses, cafeterias, buses, refuse collection, ice delivery, coal delivery and some building maintenance, are being contracted on a lump-sum or unit-price basis to firms specializing in these functions.

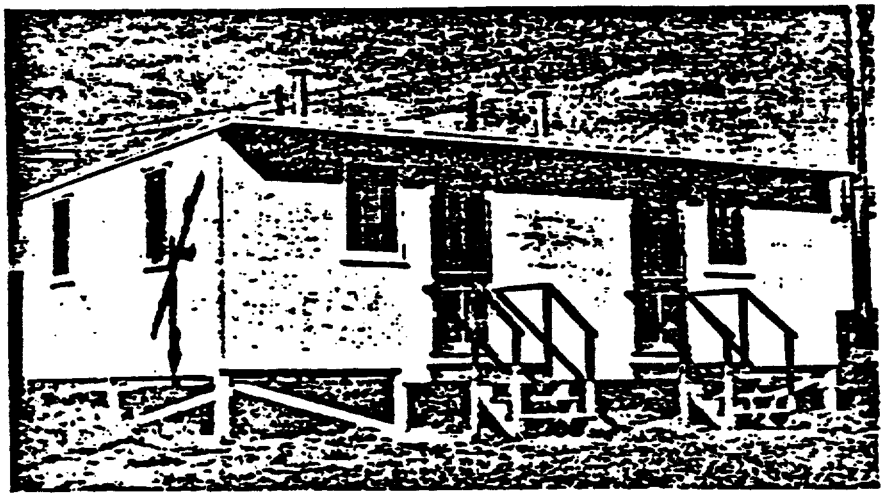
Development of several large con-



Several types of housing are grouped around the hospital, here seen getting its second addition.



TVA-type house is assembled into sections at locations sometimes as far distant from site as 650 miles, and transported by trailer or on temporary wheels to site, where a few men put a two- to four-unit house together in one day.



Marginal-type house accommodates two families in a 20 x 28-ft. structure.

struction camps paralleled the growth of the new city. During the summer of 1943, some 1,000 trailers were brought in. To serve them, laundry and toilet buildings were constructed, together with roads, walks and utilities.

At the same time, an equal number of 16-ft. square, unlined plywood huts were erected to house 5,000 construction workers, and later, a quantity of 20x100-ft. plywood barracks were purchased and set up. By the summer of 1945, the number of trailers had increased to 5,000, and three large hutment camps contained 2,500 huts. In addition, 90 barracks and 6 temporary dormitories had been erected.

In addition to the above was the construction of several large cafeterias, three of which can serve 10,000 meals per day each, recreation halls, warehouses, [illegible] houses, churches, athletic fields and other facilities essential in any normal community. A population peak of approximately 32,000 was reached in the several construction camps during the summer of 1944. Stone & Webster Engineering Corp. and the J. A. Jones Construction Co. were responsible for the construction of the majority of these facilities.

Supplementary community facilities

Nine schools, with capacities ranging from 350 to over 2,000 have been built. They are single-story, except the high school, and the majority of the buildings are composed of weather-proof insulation board on standard wood frame or prefabricated panels in a skeleton frame of posts and girders.

Two large laundries, a cold storage building and two large groups of warehouses provide service facilities to the city. The Oak Ridge Hospital, designed originally for 50 beds, has been expanded to a multi-winged structure about 650 ft. long and containing 300 beds. It is mostly of concrete block construction.

Two main shopping centers were developed in the town in addition to numerous neighborhood store groups. Designers of both centers took advantage of favorable topography in providing service entrances at basement floor levels with customer access at the first floor.

One of these shopping centers, known as "Grove Center," is noteworthy for the use of corrugated asbestos board for exterior finish providing attractive and modern fire resistant buildings at low cost. With the advantage of pre-planning, sufficient parking space was obtained convenient to the stores, thus eliminating disadvantages inherent in most city commercial areas.

Many recreation facilities

Because of the large proportion of dormitory and construction camp residents, as well as the great number of younger children natural to a city composed almost entirely of young and middle aged couples, numerous recreation facilities were essential to prevent a large labor turnover.

Community houses were constructed in the trailer camps and several recreation buildings and bowling alleys were built. Two roller skating rinks are in operation, as well as many soft ball diamonds, two base ball diamonds, 22 tennis courts, badminton courts, seven theatres, a library and similar facilities for adult recreation.

Dozens of playgrounds, for teenage children as well as tots, were constructed in the town and trailer camps. These playgrounds are supervised by a community organization. In trailer camps, where living conditions were least comfortable, extra facilities were provided in the form of wading pools. In addition, a concrete outdoor swimming pool was constructed near the center of the city. This pool is large enough for a 100-meter straightaway race course.

Much of the expense of this recreation program, including the cost of the swimming pool, was borne by a self-sustaining commuity organization set up for the purpose.

Water Supply and Sewage Works For the Atomic Bomb City

G. E. Crosby
Resident Engineer

P. B. Streander
Industrial Engineer

Stone & Webster Engineering Corp.

● *"Explosive" growth of the complete new city of Oak Ridge, Tenn., compressed into 2½ years problems of utility design and construction ordinarily spread over a century. How the city's water supply developed from its tank-wagon start to a modern 16-mgd service, and how two complete sewage systems were built to handle flow from the 75,000 population are described in the following.*

DESIGN AND CONSTRUCTION of the various utilities for the Clinton Engineer Works and its tributary city of Oak Ridge are of unusual interest to municipal engineers because of problems involved in keeping pace with the demands of the rapidly increasing population and production facilities. When the project was started it was estimated that a townsite to accommodate 5,000 would meet the housing requirements. The actual, ultimate population served was nearly 75,000.

The Clinton Engineer Works, in which Oak Ridge is situated, is located in the foothills of the Cumberland Mountain Range. The town is bounded on one side by Black Oak Ridge, at El. 1,150, and on the opposite side by Oak Ridge Turnpike, at El. 850. The residential section lies on a hill extending from the crest to the lower valley areas, where are located the business sections, trailer camps, dormitories and hutment areas. A saddle divides the town into two areas, one draining toward the Clinch River at the east and the other sloping toward Poplar Creek at the west. Served from the same utility systems is the plant for electromagnetic separation of uranium isotopes which is located in a separate valley about two miles south of the town, beyond intervening protective ridges. Stone & Webster Engineering Corp., Architect-Engineer-Manager both for this plant and for the town of Oak Ridge, built the utilities with its own forces.

Utilities for the town and the plant area were designed and constructed in five distinct stages, as follows:

1. Temporary water supply and sewerage for construction and administrative personnel during the early construction period.
2. Central townsite and original production area.
3. East village and expansion of original production area.
4. West village and new production area extension.
5. Final development of Oak Ridge and the production areas.

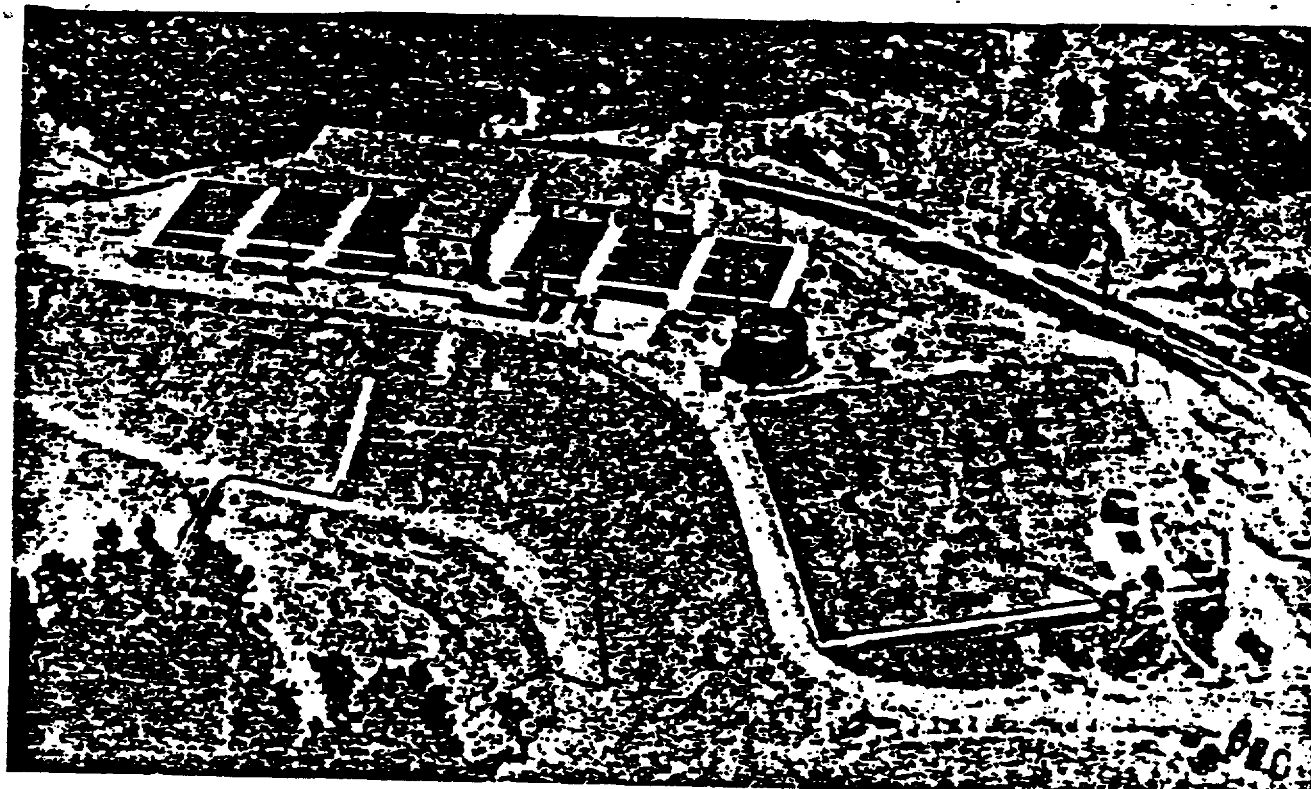
In this development the population increased from the original estimate of 5,000, first to 22,000, then to 38,000, followed by 65,000 and, ultimately, 75,000. Manufacturing facilities increased in about the same ratio. As a result, one plan was hardly developed and construction work started before changed requirements dictated the necessity of an entirely new layout.

The relentless demands of the rush

Location of 28-mgd. pump house on steep bank of Clinch River imposed considerable difficulty in anchoring two 24-in. force mains.

...at uses activated sludge process to treat ... emical oxygen demand than the receiving ... is taken farther downstream.

...ary to divide the ...stem into three pres... This was done by instal... omatic pressure reducing and ...ulating valves at the zone intersection points. Specially design... trol valves are utilized at the booster-pump houses to cut off ... matically the flow to the low-... during periods of extrem...

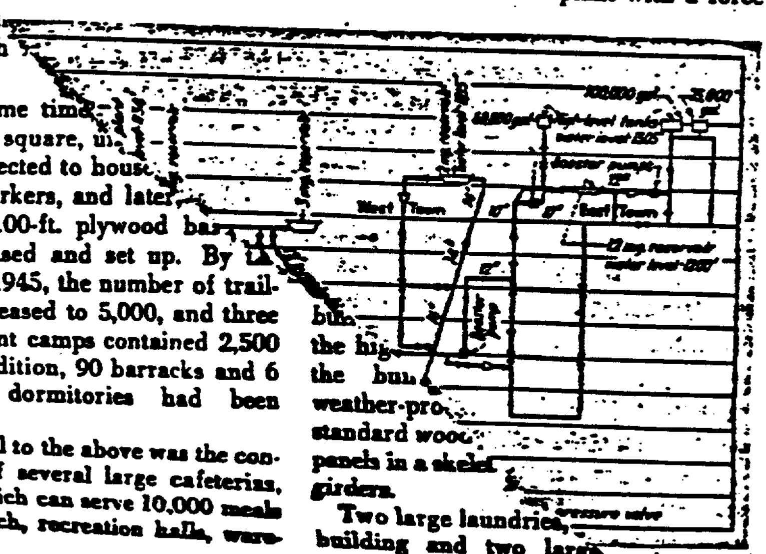


Filtration plant of 16-mgd. capacity is located 300 ft. above and 14,000 ft. away from supply source. Square at right is top of 4-mg. distribution reservoir, which is divided into two compartments.

construction schedule required great ingenuity and the utmost coordination of the various construction divisions and subcontractors in order that all phases of the work could be carried on without interruption. As a result, between March 24, 1943 and Aug. 1, 1944, when houses were being released for beneficial occupancy on an average of 16 a day, the 550 mi. of str... ...ewer and water lines were being of th... ...alled at the rate of 600 ft. per hr., of 194... ...ly a mile per 8-hr. work day. brought in... and toilet bu... together with ... ties.

At the same tim... ber of 16-ft. square, ... huts were erected to hous... struction workers, and later... tity of 20x100-ft. plywood ba... were purchased and set up. By t... summer of 1945, the number of trailers had increased to 5,000, and three large hutment camps contained 2,500 huts. In addition, 90 barracks and 6 temporary dormitories had been erected.

Incidental to the above was the construction of several large cafeterias, three of which can serve 10,000 meals per day each, recreation halls, ware-



bu... the hig... the bu... weather-pro... standard woo... panels in a skele... girders.

Two large laundries... building and two larg... ...accoust... ...ceiling

During initial construction and before there were living facilities on the project, water was hauled by tank wagons from Clinton, seven miles away. As quickly as possible, a temporary water supply system was constructed to replace the ever-increasing demand on the tank wagon supply. This temporary system consisted of a small pump house at the Clinch River with a force main to a pressure filter plant. Two booster pumps were installed at the filter plant with a force main through the townsite to a 150,000-gal. wooden storage tank located on the ridge north of the town. Raw sewage dumped into the river at Clinton, about nine miles above the temporary pump house, necessitated extreme precautions in operating the plant.

Later, this temporary water supply was connected to a 1,000,000-gal. reservoir, which eventually became a part of the permanent system. This provided a continuous supply of 200,000 gpd. until the permanent water supply was functioning.

High-level filtration plant

The permanent water supply system consists of a pump house located on the Clinch River, with force mains to a filtration plant and reservoirs located on a ridge between the production and townsite areas. These reservoirs supply the entire manufacturing area and the lower levels of the townsite by gravity. Booster pumps and high-level storage reservoirs serve high areas of the town.

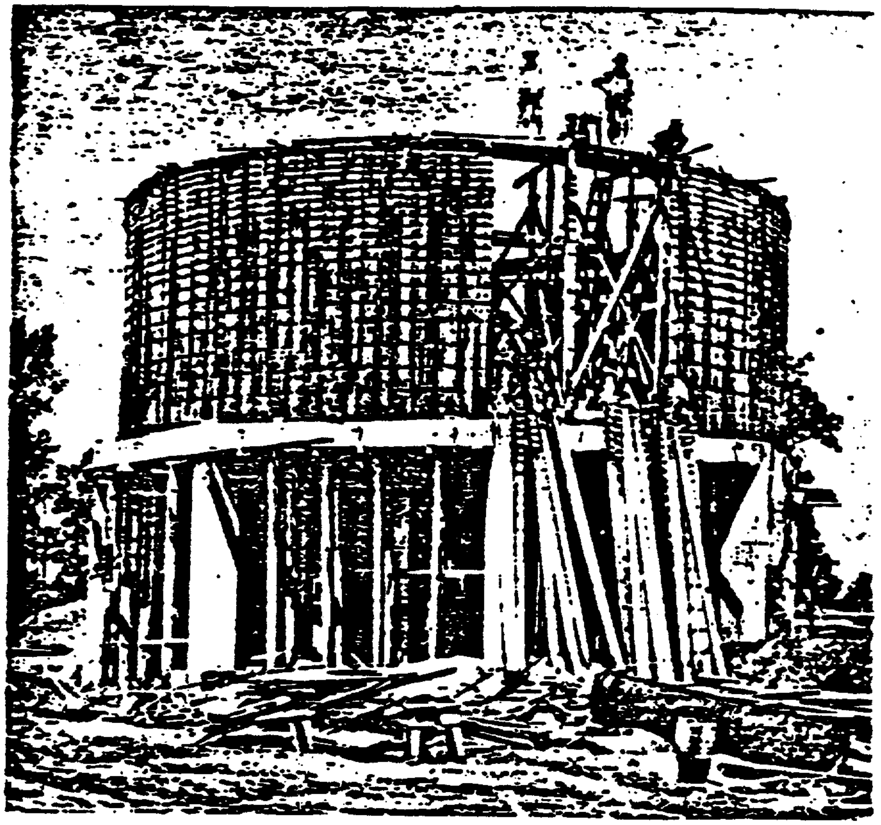
Originally the pump house contained four centrifugal pumps having a combined capacity of about 12 mgd. Later the pump house was extended to house four more pumps, increasing its total capacity to about 28 mgd. Each pump disch...

an automatically operated cone check valve and surge anticipator.

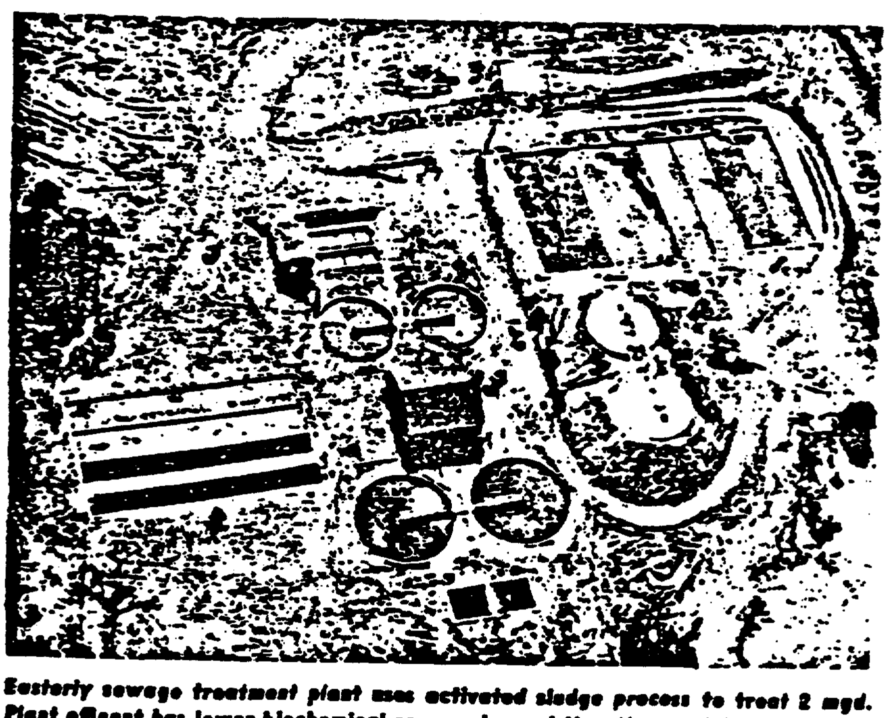
The pumps discharge into three separator manifolds connected to the force mains leading to the filtration plant. The force main installation consisted originally of about 14,000 ft. of 24-in. C.I. pipe, and subsequently was increased by a second pipeline of the same diameter and length. The two force mains are interconnected at three points and provided with sectionalizing valves.

Built to a capacity of 9 mgd. originally, the filtration plant was later enlarged to 16 mgd. Of the conventional type, it consists of a flash mixer; two flocculation tanks equipped with mechanically operated paddle mixers; two settling tanks; and 14 gravity-type filter units of concrete. Equipment for feeding aluminum sulphate and hydrated lime to the raw water, and soda-ash to the filtered water for pH control, is of the automatically-operated, gravimetric type. Facilities are provided for pre- and post-chlorination. The filters are back washed by means of motor-operated centrifugal pumps and are equipped with surface-type sand washers and the customary gages.

Alongside of the filtration plant are a 4-mg. reservoir, divided into two compartments, and another distribution reservoir of 3-mg. capacity. Two 16-in. feed lines, originally installed to supply the manufacturing area from these reservoirs, were later supplemented by an additional 24-in. line. These supply lines tie into the distribution system at three points, thereby securing more constant pressure throughout the area.



To serve high areas of the town, elevated storage tanks are supplied by booster pumping stations. This redwood tank was obtained second-hand and re-erected with the staves opposite end up from the original installation.

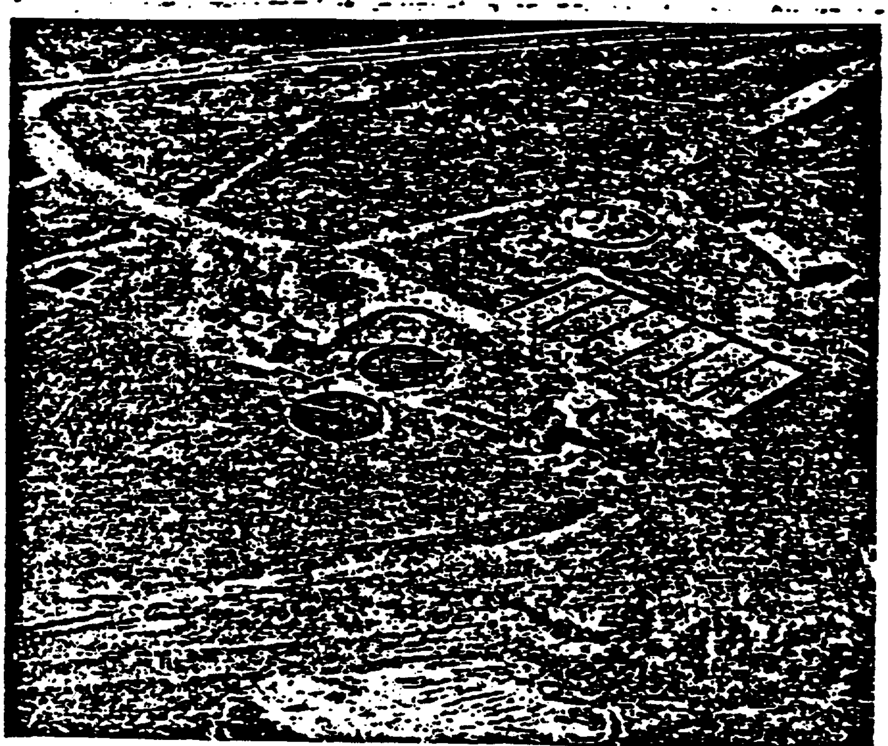


Easterly sewage treatment plant uses activated sludge process to treat 2 mgd. Plant effluent has lower biochemical oxygen demand than the receiving waterway, from which water supply is taken farther downstream.

Three pressure zones

A 12-in. supply main was originally constructed from the 4-mg. reservoir to serve as a gravity supply to the lower levels of the townsite, and an automatically-operated booster pump installation forced water to a high-level 1.2 mg. reservoir located on Black Oak Ridge at the northerly side of the town to supply the high and intermediate zones. Later, an additional 16-in. supply main was extended from the reservoir to the west townsite, with automatically-operated booster pumps to force water to a second high-level reservoir of 2-mg. capacity.

With a difference of almost 300 ft. between the high and low levels of the town, it was necessary to divide the distribution system into three pressure zones. This was done by installing automatic pressure reducing and regulating valves at the zone intersection points. Specially designed control valves are utilized at the two booster-pump houses to cut off automatically the flow to the low-level zone during periods of extreme demand,



Westerly sewage plant provides primary treatment and chlorination. Present flows of 4.5 to 6 mgd. overtax design capacity of 3.5 mgd., reducing expected treatment results. Plans call for providing chemical precipitation.

thus assuring an adequate supply to the booster pumps. During such periods the low-level zone was supplied from the high-level storage reservoirs through pressure regulating valves in the high and intermediate zones.

An uninterrupted supply of water was assured at all times by interconnecting supply mains to the booster pumps in low-pressure zones, and cross-connecting distribution mains.

Plant process water

Make-up water for a cooling tower installation, reputed to be the largest in operation at the present time, constitutes a large part of the water demand for the manufacturing area. Most of this is raw water taken directly from the force mains between the river pump house and the filtration plant. Both raw and filtered water are chemically treated to prevent scaling.

Total amounts of water used on the project closely approach designed capacities, and during warm weather the raw-water pumps and the filtration plant operate at full capacity. Controls are installed at the filtration plant so that all operations can be observed at one point. All water pumped and distributed from the filter plant is metered.

Originally the permanent system, designed for a population of 12,000, was intended only to serve the east village. A trunk sewer was laid from the manufacturing area to a pumping station where sewage was pumped over the ridge between the easterly and westerly parts of the townsites. The townsite trunk sewer is 18-in. dia. and carries the sewage to the easterly treatment plant located near the Clinch River.

Later, when the manufacturing area was expanded and the west townsite was constructed, the trunk sewer from the processing plant was extended to a new sewage treatment plant built along Poplar Creek at the westerly end of the town and about seven miles from the easterly plant. At this time the pumping plant was placed in stand-by operation. All sewage from the manufacturing area and the west townsite now flows by gravity to a westerly treatment plant through a trunk sewer varying from 18 in. to 36 in. in size.

The sewer system is, therefore, divided into two separate drainage areas—one flowing to the easterly disposal plant, where the effluent discharges into Clinch River about 10 mi. above the water supply intake; the other flowing to the westerly disposal plant, where the effluent discharges into Poplar Creek at a point 16 mi. above its confluence with the Clinch River.

The easterly sewage treatment plant, having a capacity of 2 mgd., is of the activated sludge type. It consists of a grease removal tank, primary settling tanks, aeration tanks of the air-actuated spiral-flow type, secondary settling tanks, chlorine contact tanks, two-stage heated sludge digestion tanks and open sludge drying beds.

Aeration tank design

The aeration tanks are of the return flow type and are designed so that settled sewage may be applied at four points in the first passes of the tanks. Return sludge can also be supplied at four points.

With this design, sewage can be pre-aerated before sludge is added, the sludge can be reactivated, or step loading of applied sewage can be used. During the major part of the time settled sewage flows into the first pass at two points, with return sludge added at three points. Present flows through the plant average between 1.5 and 1.85 mgd.

Operating results have been excellent, the plant effluent having a lower oxygen demand than that of water in the Clinch River at the discharge point, which is nine miles below the outfall sewer of Clinton, Tenn.

The westerly sewage plant has a designed capacity of 3.5 mgd. for primary treatment only. It consists of a grease removal tank, primary settling tanks, chlorine contact tanks, a single-stage heated sludge digestion tank and open sludge drying beds.

Chemical precipitation plant needed

Due to the final expansion of the townsite, present flows average between 4.5 and 6 mgd. High peak hourly flows also occur due to three shift operation of change houses in the production area. Under these conditions, treatment results are not up to those anticipated. Plans have been made to change the plant to the chemical precipitation type, but conversion is being held in abeyance.

Although certain process wastes from the production area are discharged into the west side trunk sewer, they are, for the most part, pretreated and, therefore, present no problem to the treatment plant except that of increased flow.